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DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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# AGINCOURT MAGNETIC DATA 1899-1937 AND THE SUNSPOT CYCLE

By W. E. W. JACKSON

THE Agincourt Magnetic Observatory was established in 1898 to replace the Toronto observatory whose records were gradually becoming useless, due to the increase in electric trolley services.

Photographic records of the variations in Declination and Horizontal Force have now been obtained for more than three sunspot periods and in Vertical Force, recording of which was started in 1914, for more than two sunspot periods.

The absolute values of the photographic base lines are controlled by frequent absolute observations of Declination, Horizontal Force and Inclination, and all results have been reduced to the International Magnetic Standard set up by the Department of Terrestrial Magnetism, Carnegie Institution of Washington. The corrections to be applied to the Agincourt instruments were determined by intercomparisons with the Washington instruments made both at Agincourt and Washington on several occasions during this period.

From 1899 to 1921, inclusive, the ordinates of the curves were measured exactly at the hour. From 1922 to June, 1932, the values taken were average values of the ordinate for an hour centred on the hour, and from July, 1932, the values have been the average value for an hour centred on the half-hour. Up to June, 1932, the 75th meridian civil day has been used in computing daily means and from July, 1932, the Greenwich civil day. The daily value is the mean of the 24 hourly values and the monthly value is the mean of all the daily values in the month. The yearly value is the mean of the twelve monthly values. In tables 1, 2 and 3 a

summary of the mean annual values of Agincourt Declination, Horizontal and Vertical Force is given, together with the annual change. In the case of Vertical Force the values from 1899 to 1914, inclusive, are obtained from the average value of the Inclination observed each month combined with the mean Horizontal Force. The equation relating these elements is

$$\text{Vertical Force} = \text{Horizontal Force} \times \text{tangent } I$$

The resulting values for Vertical Force over this period are less accurate than later values but still do depict fairly well the trend of Vertical Force over the period. These are plotted as the full curve in chart 1.

On examination it is readily seen that the curve of annual values can fairly approximately be represented by the formula

$$E = a + bt + ct^2,$$

where $E$ is the element under consideration and $a$, $b$ and $c$ are constants and $t$ the time in years reckoned from some convenient year, in this case 1918.5.

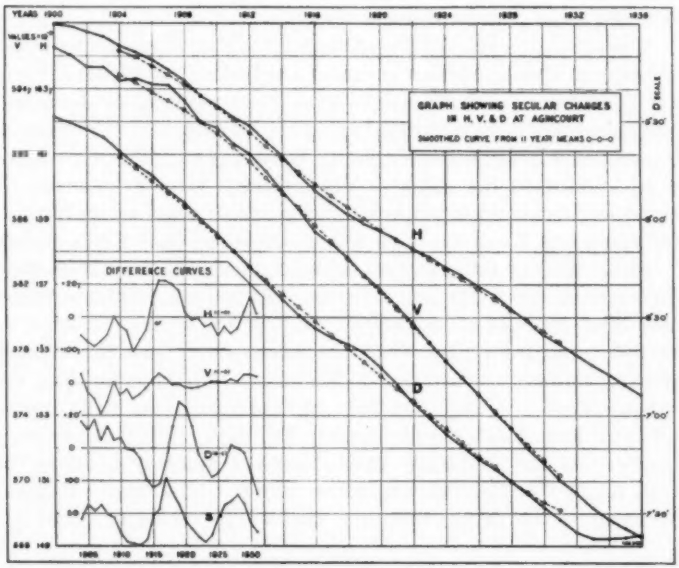


Chart 1.—Secular changes in $H$, $V$ and $D$ at Agincourt.

As $V$ is less reliable in the early years, its computation has not been made, but for $D$ and $H$ the constants derived by least squares from 37 equations of condition are for Declination, which is considered negative when westerly,

$$a = -6°40'.53;\ b = -4'.00;\ c = +0'.021$$

and for Horizontal Force

$$a = 15953.1\ \gamma;\ b = -33.41\ \gamma;\ c = 0.0015\ \gamma.$$

The theoretical curve in both $D$ and $H$ departs only slightly from a straight line, and the differences between theoretical and observed values in both elements suggest an influence at work that varies with the sunspot cycle.

Introducing a factor into the equation that varies with the Wolfer sunspot number, the equation becomes

$$E = a + bt + ct^2 + d(R - 80.6)$$

where $a$, $b$, $c$ and $d$ are constants and $R$ is the Wolfer sunspot number and 80.6 is introduced to simplify the computation, and $t$, as before, is the time in years reckoned from 1918.5.

The values of the constants for Declination derived by least squares from the 37 equations of condition are now

$$a = -6°36'.4;\ b = -4'.00;\ c = +0'.021;\ d = -0'.07,$$

and those for $H$

$$a = 15945.3\ \gamma;\ b = -33.34\ \gamma;\ c = -0.01\ \gamma;\ d = -0.21\ \gamma.$$

From this it is seen that when the sunspot numbers increase by 100 the westerly Declination increases by 7 minutes of arc and the Horizontal Force decreases more rapidly some 21 gammas.

Checking this in another way by taking 11-year means, on the assumption that the period of oscillation of this movement is synchronous with the sunspot period, and plotting these results as broken curve, chart 1, and then taking differences between this smoothed curve and the original observed curve and plotting these differences as inset on chart 1, there is seen to be a striking resemblance in the curves so obtained and the sunspot curve, which is also plotted for convenience of reference. It is easy to see that for a change of 100 in the sunspot number the change in $D$ is of the order of 5'.5 and for $H$ of 35 $\gamma$ and for $V$ in the latter part of the difference curve, where values are known to be more accurate, of about 40 $\gamma$.

It must not, however, be assumed that sunspots are the cause

of these variations in magnetic phenomena on the earth, but rather, until the cause is definitely established, that there is some force at work in the sun which is variable in its action through an eleven-year period, and the result of its activity is made evident in two distinctly different phenomena, spots on the surface of the sun, and variations in the magnetic field of the earth.

Tables 4, 5 and 6 contain the mean monthly and annual diurnal variations of the three elements, obtained from the mean monthly diurnal inequalities which have been published in the annual Report of the Agincourt Magnetic Observatory.

The mean annual diurnal variations have been plotted in chart 2, as well as the Wolfer sunspot numbers.

If the variations are expressed as a linear function of the sunspot numbers of the form $E=a+bR$, and the constants $a$ and $b$ are determined by least squares from the 38 equations so formed (22 in the case of $V$), the following results are obtained for the different elements—

$$D=8'.57+0.034R$$
$$H=27.8\ \gamma+0.247R$$
$$V=\ 6.0\ \gamma+0.240R$$

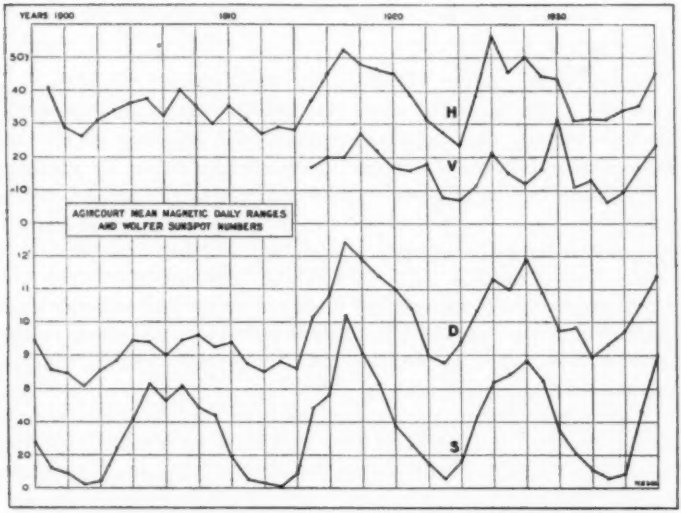


Chart 2.—Mean Magnetic Daily Ranges and Wolfer Sunspot Numbers.

Using these equations, the values have been computed for the different years and are tabulated in table 7 along with the observed values, and the differences between the computed and observed values are also given.

In the case of $D$ the average difference equals 0.46 of a minute of arc, and for $H$ and $V$ these differences are respectively 3.1 and 4.5 gammas.

From month to month throughout the year the diurnal ranges also exhibit large variations, as is clearly seen in tables 4, 5 and 6. The average monthly values of the ranges in the various elements have been determined for various groupings of years. To eliminate the eleven-year variation, three groups of eleven years each, 1900 to 1910, 1911 to 1921, and 1922 to 1932, have been chosen and averages taken. Also the full period, 1900 to 1932, and three maximum spot years, 1905, 1917 and 1928, and three minimum spot years, 1902, 1913 and 1923, were taken for $D$ and $H$. For the $V$ only one eleven-year period was used, 1922 to 1932, and three years of spot numbers, 1917, 1926 and 1936. Only two minimum spot years were available for $V$, 1923 and 1933. In the $V$ these years are, of course, not the same as the ones used for $D$ and $H$, but the average value of the sunspot numbers is not very different. The means for the different groups are tabulated in table 8 and are shown in graphical form in chart 3.

The maximum range occurs in August and the minimum in December in all groupings of Declination. In the Horizontal Force the minimum occurs in February in the 1900-to-1910 group, and the remainder are in August and December as in Declination. The Vertical Force is less regular but there is a markedly lower value during the winter months than in the summer months.

Using the shorter period, 1915 to 1936, during which data are available for all three elements, and the diurnal variation curves (see chart 2) follow more closely the sunspot curve, the evaluation of the constants in the general equation $E=a+bR$ gives the following results:

$$D=7'.63+0.056R$$
$$H=24.4\,\gamma+0.330R$$
$$V=\ 8.2\,\gamma+0.185R$$

To show how these constants vary with the month, the equations have also been computed for the months of August and December,

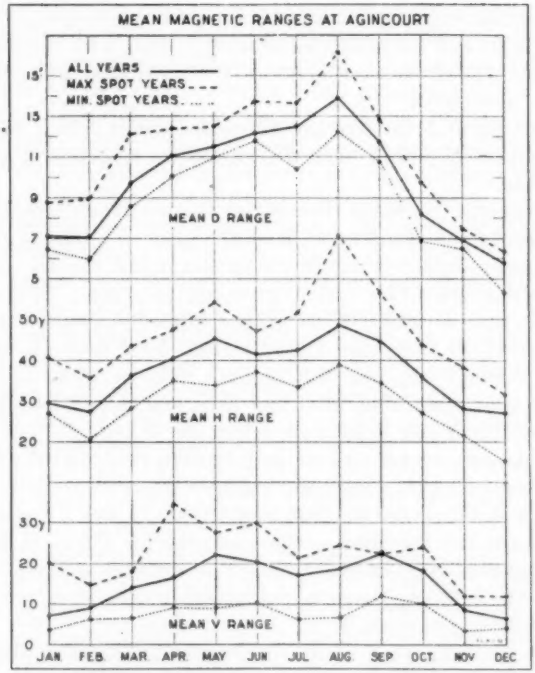


Chart 3.—Mean Magnetic Ranges at Agincourt.

using the values of the sunspot number $R$ for the particular month as published by Wolfer in *Astronomische Mitteilungen*. The results are as follows:

$$D \text{ August} = 12'.69 + 0.040R$$
$$D \text{ December} = 5.59 + 0.014R$$

$$H \text{ August} = 39.53\,\gamma + 0.288R$$
$$H \text{ December} = 17.88\,\gamma + 0.169R$$

$$V \text{ August} = 11.86\,\gamma + 0.174R$$
$$V \text{ December} = 3.62\,\gamma + 0.120R$$

Dominion Observatory,
Ottawa, October, 1939.

Table 1—Mean Monthly and Annual Values of Magnetic Declination West at Agincourt*

| | J | F | M | A | M | J | J | A | S | O | N | D | Year | Ann'l Ch'ge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ° ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ° ′ | |
| 1899 | 5 27.3 | 23.8 | 28.2 | 82.1 | 27.9 | 26.5 | 26.6 | 27.4 | 27.7 | 28.1 | 28.1 | 28.4 | 5 27.7 | |
| 1900 | 5 28.4 | 28.5 | 29.2 | 29.1 | 28.5 | 28.1 | 28.1 | 28.9 | 28.7 | 29.1 | 29.3 | 29.4 | 5 28.8 | 1.1 |
| 1901 | 5 29.5 | 29.7 | 30.1 | 30.5 | 30.4 | 30.1 | 30.4 | 30.8 | 30.8 | 30.7 | 30.9 | 31.4 | 5 30.4 | 1.6 |
| 1902 | 5 31.4 | 31.8 | 32.1 | 32.5 | 32.5 | 32.5 | 32.5 | 32.8 | 33.0 | 33.1 | 33.5 | 33.5 | 5 32.6 | 2.2 |
| 1903 | 5 34.0 | 34.0 | 34.1 | 34.8 | 34.3 | 34.5 | 34.6 | 35.2 | 35.3 | 35.9 | 36.6 | 36.8 | 5 35.0 | 2.4 |
| 1904 | 5 37.9 | 38.1 | 39.1 | 38.7 | 38.7 | 38.6 | 39.0 | 39.5 | 39.9 | 40.7 | 40.7 | 40.6 | 5 39.3 | 4.3 |
| 1905 | 5 41.1 | 41.5 | 42.0 | 43.2 | 43.7 | 43.7 | 43.2 | 43.1 | 43.5 | 44.4 | 44.4 | 43.6 | 5 43.2 | 3.9 |
| 1906 | 5 43.7 | 44.2 | 44.4 | 44.8 | 44.6 | 44.5 | 45.5 | 48.2 | 48.2 | 48.4 | 48.6 | 49.8 | 5 46.3 | 3.1 |
| 1907 | 5 49.6 | 50.0 | 49.9 | 50.2 | 50.7 | 50.6 | 50.9 | 52.0 | 52.6 | 53.7 | 53.6 | 53.7 | 5 51.5 | 5.2 |
| 1908 | 5 53.2 | 53.8 | 53.5 | 54.3 | 53.6 | 53.4 | 53.5 | 55.5 | 57.0 | 56.7 | 57.4 | 57.5 | 5 55.0 | 3.5 |
| 1909 | 5 58.2 | 58.5 | 59.1 | 59.3 | 59.8 | 59.3 | 59.9 | 60.3 | 61.2 | 62.7 | 62.4 | 62.6 | 6 0.3 | 5.3 |
| 1910 | 6 2.7 | 2.7 | 3.5 | 3.9 | 3.9 | 4.3 | 4.5 | 5.5 | 5.9 | 6.2 | 6.9 | 7.0 | 6 4.8 | 4.5 |
| 1911 | 6 7.5 | 8.1 | 8.3 | 9.1 | 9.3 | 9.1 | 9.6 | 10.4 | 11.1 | 11.5 | 12.2 | 12.7 | 6 9.9 | 5.1 |
| 1912 | 6 13.2 | 13.2 | 13.5 | 13.9 | 14.3 | 15.0 | 15.5 | 15.6 | 15.6 | 14.6 | 15.0 | 15.7 | 6 14.6 | 4.7 |
| 1913 | 6 16.5 | 17.3 | 18.0 | 18.7 | 18.9 | 19.2 | 19.7 | 20.2 | 20.4 | 20.3 | 20.8 | 21.6 | 6 19.3 | 4.7 |
| 1914 | 6 22.2 | 22.8 | 23.2 | 23.9 | 23.8 | 24.0 | 24.7 | 25.8 | 26.3 | 26.5 | 26.9 | 26.8 | 6 24.8 | 5.5 |
| 1915 | 6 27.4 | 27.9 | 28.1 | 29.0 | 28.8 | 29.2 | 29.2 | 29.5 | 30.1 | 30.8 | 31.5 | 31.2 | 6 29.4 | 4.6 |
| 1916 | 6 31.9 | 32.2 | 33.0 | 32.9 | 32.9 | 32.3 | 33.1 | 33.7 | 34.1 | 34.4 | 34.8 | 35.0 | 6 33.4 | 4.0 |
| 1917 | 6 35.5 | 35.4 | 35.6 | 35.9 | 35.7 | 34.9 | 35.4 | 36.6 | 36.5 | 37.0 | 37.6 | 38.0 | 6 36.2 | 2.8 |
| 1918 | 6 38.1 | 37.7 | 38.1 | 38.1 | 38.4 | 37.8 | 37.3 | 38.0 | 38.4 | 39.0 | 39.2 | 39.7 | 6 38.3 | 2.1 |
| 1919 | 6 39.0 | 39.6 | 40.2 | 40.4 | 40.2 | 39.9 | 40.2 | 41.8 | 42.2 | 42.5 | 42.5 | 42.9 | 6 41.0 | 2.7 |
| 1920 | 6 43.4 | 43.7 | 44.8 | 44.5 | 44.7 | 44.1 | 45.1 | 46.3 | 46.9 | 47.1 | 47.2 | 47.5 | 6 45.4 | 4.4 |
| 1921 | 6 48.2 | 48.2 | 49.1 | 49.4 | 50.2 | 49.7 | 50.1 | 51.0 | 51.8 | 52.5 | 53.2 | 53.6 | 6 50.6 | 5.2 |
| 1922 | 6 53.8 | 54.6 | 55.0 | 55.2 | 55.6 | 55.6 | 56.1 | 56.7 | 57.2 | 58.1 | 58.2 | 58.5 | 6 56.2 | 5.6 |
| 1923 | 6 58.6 | 59.3 | 60.0 | 60.3 | 60.4 | 60.2 | 60.0 | 61.9 | 61.7 | 62.2 | 62.7 | 63.4 | 7 0.9 | 4.7 |
| 1924 | 7 3.8 | 4.1 | 4.4 | 4.9 | 5.0 | 5.7 | 5.8 | 6.1 | 6.8 | 7.2 | 7.7 | 7.6 | 7 5.8 | 4.9 |
| 1925 | 7 7.8 | 8.5 | 8.5 | 9.0 | 8.8 | 9.1 | 9.2 | 9.9 | 10.6 | 11.4 | 11.5 | 11.7 | 7 9.7 | 3.9 |
| 1926 | 7 12.0 | 12.6 | 12.8 | 13.3 | 12.5 | 12.7 | 12.6 | 13.3 | 14.0 | 14.5 | 14.7 | 15.3 | 7 13.4 | 3.7 |
| 1927 | 7 15.2 | 15.7 | 15.9 | 16.1 | 15.8 | 15.2 | 15.5 | 16.5 | 17.1 | 17.9 | 17.8 | 18.3 | 7 16.4 | 3.0 |
| 1928 | 7 18.3 | 18.6 | 19.3 | 19.9 | 19.8 | 19.4 | 20.4 | 20.7 | 21.1 | 22.0 | 22.1 | 22.0 | 7 20.3 | 3.9 |
| 1929 | 7 22.4 | 22.9 | 23.7 | 23.3 | 23.3 | 23.2 | 23.6 | 24.2 | 24.4 | 25.1 | 25.6 | 26.0 | 7 24.0 | 3.7 |
| 1930 | 7 26.8 | 26.7 | 26.3 | 27.0 | 27.6 | 27.8 | 27.8 | 28.2 | 29.0 | 29.8 | 29.8 | 30.0 | 7 28.1 | 4.1 |
| 1931 | 7 30.2 | 30.6 | 30.8 | 31.0 | 31.3 | 31.1 | 31.7 | 31.5 | 33.1 | 34.0 | 33.8 | 34.2 | 7 31.9 | 3.8 |
| 1932 | 7 34.3 | 34.7 | 35.2 | 35.3 | 35.5 | 35.3 | 35.5 | 35.8 | 36.6 | 37.0 | 37.2 | 37.6 | 7 35.8 | 3.9 |
| 1933 | 7 37.3 | 37.5 | 37.7 | 38.1 | 38.3 | 36.7 | 37.2 | 37.6 | 37.7 | 37.8 | 38.0 | 38.0 | 7 37.7 | 1.9 |
| 1934 | 7 37.6 | 38.0 | 38.1 | 38.1 | 37.7 | 37.3 | 37.3 | 38.0 | 38.1 | 38.0 | 37.8 | 37.6 | 7 37.8 | 0.1 |
| 1935 | 7 37.5 | 37.5 | 37.7 | 37.4 | 37.3 | 37.4 | 36.9 | 37.1 | 36.4 | 37.9 | 37.9 | 38.0 | 7 37.4 | −0.4 |
| 1936 | 7 37.6 | 37.9 | 37.5 | 37.8 | 36.9 | 36.3 | 35.8 | 36.1 | 36.3 | 36.9 | 36.7 | 36.3 | 7 36.8 | −0.6 |

**Table 2—Mean Monthly and Annual Values of Horizontal Magnetic Force at Agincourt**
**15000γ plus tabular quantities**

| | J | F | M | A | M | J | J | A | S | O | N | D | Year | Annu'l Cha'ge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1899 | 1490 | 1483 | 1382 | 1486 | 1494 | 1508 | 1502 | 1494 | 1492 | 1484 | 1491 | 1492 | 1491.2 | |
| 1900 | 1492 | 1498 | 1494 | 1496 | 1498 | 1504 | 1504 | 1498 | 1492 | 1490 | 1494 | 1496 | 1496.5 | + 5.3 |
| 1901 | 1494 | 1492 | 1488 | 1494 | 1494 | 1494 | 1492 | 1486 | 1482 | 1484 | 1488 | 1488 | 1489.4 | − 7.1 |
| 1902 | 1484 | 1482 | 1480 | 1476 | 1480 | 1478 | 1460 | 1456 | 1462 | 1464 | 1470 | 1476 | 1472.2 | −17.2 |
| 1903 | 1478 | 1478 | 1476 | 1470 | 1472 | 1472 | 1468 | 1458 | 1448 | 1435 | 1425 | 1435 | 1459.3 | −12.9 |
| 1904 | 1436 | 1438 | 1436 | 1426 | 1426 | 1434 | 1438 | 1430 | 1420 | 1416 | 1418 | 1424 | 1428.7 | −30.6 |
| 1905 | 1420 | 1418 | 1412 | 1418 | 1424 | 1422 | 1422 | 1414 | 1402 | 1400 | 1384 | 1394 | 1410.6 | −18.1 |
| 1906 | 1394 | 1390 | 1390 | 1396 | 1394 | 1396 | 1396 | 1386 | 1378 | 1376 | 1380 | 1374 | 1387.4 | −23.2 |
| 1907 | 1368 | 1352 | 1362 | 1370 | 1366 | 1366 | 1362 | 1358 | 1345 | 1364 | 1362 | 1348 | 1356.9 | −30.5 |
| 1908 | 1344 | 1338 | 1330 | 1332 | 1328 | 1332 | 1336 | 1325 | 1308 | 1300 | 1294 | 1300 | 1322.2 | −34.7 |
| 1909 | 1289 | 1288 | 1280 | 1290 | 1284 | 1294 | 1292 | 1282 | 1264 | 1240 | 1262 | 1264 | 1277.4 | −44.8 |
| 1910 | 1268 | 1265 | 1252 | 1248 | 1256 | 1264 | 1260 | 1237 | 1240 | 1224 | 1230 | 1230 | 1247.7 | −29.7 |
| 1911 | 1224 | 1220 | 1213 | 1215 | 1214 | 1222 | 1218 | 1216 | 1202 | 1192 | 1202 | 1195 | 1211.2 | −36.5 |
| 1912 | 1200 | 1196 | 1194 | 1192 | 1194 | 1195 | 1190 | 1181 | 1178 | 1169 | 1170 | 1156 | 1184.4 | −26.8 |
| 1913 | 1156 | 1158 | 1155 | 1147 | 1146 | 1148 | 1142 | 1124 | 1122 | 1116 | 1120 | 1113 | 1137.2 | −47.2 |
| 1914 | 1122 | 1121 | 1112 | 1100 | 1104 | 1102 | 1093 | 1082 | 1072 | 1066 | 1062 | 1066 | 1091.9 | −45.3 |
| 1915 | 1060 | 1052 | 1045 | 1047 | 1049 | 1033 | 1040 | 1032 | 1023 | 1010 | 1004 | 1013 | 1034.1 | −57.8 |
| 1916 | 1004 | 1009 | 989 | 999 | 998 | 1002 | 989 | 978 | 971 | 967 | 967 | 972 | 987.1 | −47.0 |
| 1917 | 960 | 963 | 961 | 961 | 963 | 963 | 956 | 932 | 939 | 934 | 937 | 936 | 950.4 | −36.7 |
| 1918 | 941 | 930 | 925 | 921 | 924 | 928 | 924 | 910 | 902 | 895 | 898 | 892 | 915.8 | −34.6 |
| 1919 | 896 | 894 | 884 | 894 | 891 | 903 | 897 | 873 | 866 | 863 | 878 | 878 | 884.8 | −31.0 |
| 1920 | 884 | 881 | 858 | 864 | 876 | 877 | 872 | 867 | 849 | 846 | 851 | 856 | 865.1 | −19.7 |
| 1921 | 854 | 857 | 852 | 851 | 831 | 846 | 843 | 837 | 826 | 822 | 825 | 825 | 839.1 | −26.0 |
| 1922 | 821 | 817 | 810 | 816 | 816 | 820 | 813 | 806 | 798 | 794 | 800 | 801 | 809.3 | −29.8 |
| 1923 | 799 | 794 | 790 | 790 | 791 | 790 | 788 | 782 | 777 | 767 | 768 | 768 | 783.7 | −25.6 |
| 1924 | 760 | 761 | 761 | 763 | 756 | 755 | 755 | 753 | 739 | 742 | 736 | 740 | 751.8 | −31.9 |
| 1925 | 733 | 730 | 741 | 738 | 738 | 735 | 735 | 729 | 711 | 709 | 712 | 711 | 727.7 | −24.1 |
| 1926 | 699 | 692 | 691 | 693 | 699 | 704 | 706 | 697 | 680 | 677 | 684 | 682 | 692.1 | −35.6 |
| 1927 | 686 | 672 | 659 | 669 | 671 | 682 | 670 | 660 | 654 | 640 | 652 | 648 | 663.6 | −28.5 |
| 1928 | 650 | 650 | 647 | 647 | 641 | 639 | 620 | 615 | 611 | 602 | 606 | 612 | 628.3 | −35.3 |
| 1929 | 610 | 598 | 581 | 599 | 602 | 602 | 592 | 587 | 573 | 568 | 565 | 559 | 586.3 | −42.0 |
| 1930 | 562 | 558 | 554 | 554 | 553 | 552 | 551 | 539 | 525 | 522 | 528 | 529 | 543.9 | −42.4 |
| 1931 | 534 | 531 | 528 | 531 | 532 | 532 | 529 | 517 | 508 | 497 | 500 | 501 | 520.0 | −23.9 |
| 1932 | 496 | 492 | 486 | 487 | 493 | 498 | 497 | 484 | 475 | 472 | 468 | 467 | 484.6 | −35.4 |
| 1933 | 464 | 461 | 458 | 458 | 460 | 466 | 463 | 450 | 438 | 443 | 441 | 438 | 453.3 | −31.3 |
| 1934 | 433 | 429 | 423 | 430 | 431 | 432 | 427 | 423 | 414 | 413 | 417 | 409 | 423.4 | −29.9 |
| 1935 | 403 | 395 | 394 | 398 | 404 | 403 | 399 | 397 | 372 | 375 | 374 | 372 | 390.5 | −32.9 |
| 1936 | 368 | 364 | 366 | 366 | 375 | 373 | 367 | 369 | 365 | 349 | 341 | 346 | 362.5 | −28.0 |

Table 3—Mean Monthly and Annual Values at Vertical Magnetic Force at Agincourt
56000 γ plus tabular quantities

| | J | F | M | A | M | J | J | A | S | O | N | D | Year | Ann'l Cha'ge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1915 | 2714 | 2707 | 2686 | 2673 | 2671 | 2657 | 2659 | 2657 | 2635 | 2627 | 2608 | 2588 | 2657 | |
| 1916 | 2574 | 2574 | 2572 | 2559 | 2537 | 2532 | 2520 | 2510 | 2523 | 2523 | 2513 | 2518 | 2538 | −119 |
| 1917 | 2508 | 2496 | 2486 | 2462 | 2448 | 2436 | 2422 | 2441 | 2426 | 2411 | 2422 | 2433 | 2449 | − 89 |
| 1918 | 2425 | 2416 | 2405 | 2392 | 2365 | 2360 | 2348 | 2346 | 2334 | 2342 | 2333 | 2324 | 2366 | − 83 |
| 1919 | 2317 | 2313 | 2300 | 2281 | 2273 | 2250 | 2240 | 2234 | 2228 | 2233 | 2221 | 2224 | 2260 | −106 |
| 1920 | 2230 | 2224 | 2221 | 2202 | 2179 | 2164 | 2146 | 2139 | 2129 | 2122 | 2115 | 2122 | 2166 | − 94 |
| 1921 | 2106 | 2104 | 2095 | 2087 | 2083 | 2073 | 2064 | 2047 | 2046 | 2031 | 2022 | 2020 | 2065 | −101 |
| 1922 | 2017 | 2000 | 2000 | 1990 | 1972 | 1966 | 1953 | 1932 | 1932 | 1927 | 1929 | 1916 | 1961 | −104 |
| 1923 | 1898 | 1894 | 1887 | 1870 | 1851 | 1858 | 1849 | 1827 | 1817 | 1818 | 1812 | 1798 | 1849 | −112 |
| 1924 | 1788 | 1789 | 1769 | 1747 | 1725 | 1723 | 1730 | 1723 | 1718 | 1701 | 1698 | 1687 | 1733 | −116 |
| 1925 | 1671 | 1660 | 1654 | 1639 | 1634 | 1634 | 1622 | 1605 | 1607 | 1607 | 1610 | 1591 | 1628 | −105 |
| 1926 | 1583 | 1579 | 1578 | 1558 | 1540 | 1524 | 1513 | 1504 | 1497 | 1492 | 1483 | 1478 | 1527 | −101 |
| 1927 | 1472 | 1454 | 1448 | 1439 | 1418 | 1404 | 1406 | 1404 | 1393 | 1381 | 1368 | 1353 | 1412 | −115 |
| 1928 | 1350 | 1359 | 1352 | 1335 | 1315 | 1314 | 1313 | 1296 | 1291 | 1296 | 1289 | 1267 | 1515 | − 97 |
| 1929 | 1263 | 1256 | 1238 | 1214 | 1206 | 1202 | 1186 | 1173 | 1162 | 1153 | 1150 | 1147 | 1196 | −119 |
| 1930 | 1150 | 1150 | 1133 | 1131 | 1127 | 1126 | 1100 | 1076 | 1064 | 1064 | 1065 | 1053 | 1103 | − 93 |
| 1931 | 1047 | 1040 | 1029 | 1022 | 1022 | 1012 | 1002 | 999 | 990 | 992 | 988 | 978 | 1010 | − 93 |
| 1932 | 954 | 948 | 949 | 943 | 939 | 935 | 917 | 909 | 914 | 901 | 894 | 882 | 924 | − 86 |
| 1933 | 869 | 858 | 858 | 858 | 855 | 845 | 832 | 812 | 817 | 821 | 816 | 798 | 837 | − 87 |
| 1934 | 775 | 765 | 779 | 780 | 765 | 754 | 747 | 754 | 757 | 751 | 751 | 764 | 762 | − 75 |
| 1935 | 741 | 720 | 719 | 719 | 726 | 710 | 702 | 689 | 684 | 705 | 706 | 680 | 708 | − 54 |
| 1936 | 681 | 676 | 686 | 687 | 676 | 649 | 652 | 649 | 640 | 638 | 629 | 623 | 657 | − 51 |

**Table 4—Mean Monthly Diurnal Ranges from 24-hour Readings of *D* at Agincourt**

| | Jan. | Feb. | Mar. | Apl. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1899.. | 6.51 | 6.93 | 7.84 | 8.35 | 10.01 | 10.96 | 11.44 | 13.15 | 9.89 | 6.91 | 5.76 | 4.91 | 8.56 |
| 1900.. | 6.07 | 5.72 | 7.38 | 9.57 | 10.12 | 11.13 | 11.31 | 12.50 | 10.96 | 7.10 | 5.73 | 4.10 | 8.47 |
| 1901.. | 5.08 | 5.54 | 8.04 | 8.77 | 9.29 | 10.47 | 10.52 | 12.50 | 10.33 | 6.92 | 5.48 | 3.83 | 8.06 |
| 1902.. | 6.27 | 5.63 | 7.89 | 9.07 | 10.41 | 11.07 | 10.50 | 13.44 | 11.07 | 7.13 | 6.23 | 4.06 | 8.56 |
| 1903.. | 5.93 | 6.56 | 8.03 | 8.55 | 10.56 | 12.15 | 11.93 | 12.67 | 10.45 | 6.58 | 6.27 | 6.28 | 8.83 |
| 1904.. | 6.84 | 6.75 | 8.89 | 10.16 | 10.96 | 11.74 | 11.62 | 15.06 | 11.39 | 8.82 | 5.50 | 5.69 | 9.45 |
| 1905.. | 6.64 | 6.41 | 10.13 | 10.19 | 11.36 | 11.21 | 11.57 | 13.59 | 11.00 | 7.93 | 7.30 | 5.37 | 9.39 |
| 1906.. | 7.09 | 6.25 | 9.50 | 11.77 | 10.55 | 9.38 | 11.55 | 12.82 | 10.96 | 6.97 | 6.36 | 4.90 | 9.01 |
| 1907.. | 6.47 | 7.28 | 10.86 | 11.47 | 10.76 | 11.79 | 11.10 | 12.02 | 12.39 | 6.54 | 7.00 | 5.36 | 9.42 |
| 1908.. | 5.72 | 7.58 | 8.93 | 10.14 | 11.62 | 9.13 | 12.48 | 15.01 | 12.73 | 9.24 | 6.61 | 6.62 | 9.65 |
| 1909.. | 6.86 | 6.16 | 9.13 | 10.79 | 10.06 | 11.15 | 11.37 | 13.03 | 10.57 | 7.73 | 7.07 | 7.04 | 9.25 |
| 1910.. | 6.50 | 7.96 | 9.10 | 10.52 | 9.16 | 11.66 | 12.21 | 12.55 | 10.13 | 9.18 | 7.37 | 6.89 | 9.44 |
| 1911.. | 6.74 | 5.80 | 7.17 | 9.10 | 9.53 | 11.55 | 11.94 | 13.16 | 11.35 | 8..0 | 5.35 | 5.12 | 8.73 |
| 1912.. | 4.33 | 5.22 | 9.43 | 10.20 | 11.30 | 10.56 | 11.45 | 12.11 | 9.27 | 7.71 | 5.67 | 5.15 | 8.53 |
| 1913.. | 5.73 | 5.43 | 8.90 | 9.46 | 11.78 | 12.41 | 10.83 | 12.52 | 10.66 | 7.31 | 6.45 | 4.46 | 8.83 |
| 1914.. | 4.72 | 4.23 | 8.42 | 10.86 | 10.40 | 11.48 | 11.56 | 13.24 | 11.48 | 6.17 | 5.29 | 5.80 | 8.64 |
| 1915.. | 6.88 | 6.65 | 10.06 | 11.91 | 12.78 | 11.37 | 13.53 | 14.35 | 11.85 | 8.07 | 8.15 | 6.47 | 10.17 |
| 1916.. | 7.75 | 8.07 | 10.37 | 13.21 | 12.69 | 13.77 | 13.14 | 14.77 | 12.24 | 9.14 | 8.44 | 5.92 | 10.79 |
| 1917.. | 9.02 | 9.73 | 14.13 | 13.04 | 14.09 | 15.77 | 14.47 | 17.07 | 14.98 | 10.61 | 8.79 | 7.22 | 12.41 |
| 1918.. | 7.23 | 9.02 | 12.42 | 13.65 | 14.18 | 13.28 | 15.36 | 17.48 | 14.95 | 10.12 | 8.51 | 6.55 | 11.90 |
| 1919.. | 10.53 | 7.64 | 9.86 | 13.65 | 11.53 | 15.55 | 14.89 | 16.65 | 13.53 | 10.11 | 6.77 | 6.24 | 11.42 |
| 1920.. | 8.64 | 9.42 | 11.25 | 11.89 | 12.89 | 13.50 | 14.19 | 13.94 | 11.92 | 9.17 | 8.67 | 6.49 | 11.00 |
| 1921.. | 6.57 | 6.69 | 10.43 | 10.73 | 12.24 | 12.26 | 15.04 | 14.57 | 12.41 | 9.52 | 7.46 | 6.34 | 10.36 |
| 1922.. | 5.35 | 6.55 | 9.33 | 10.90 | 11.81 | 11.61 | 12.21 | 12.49 | 9.85 | 6.66 | 6.41 | 4.91 | 9.01 |
| 1923.. | 7.36 | 6.82 | 8.93 | 11.71 | 10.72 | 11.90 | 9.77 | 10.56 | 10.30 | 6.18 | 6.79 | 4.36 | 8.78 |
| 1924.. | 7.62 | 5.35 | 8.57 | 8.88 | 10.86 | 11.86 | 12.59 | 13.68 | 11.97 | 8.89 | 7.12 | 5.64 | 9.42 |
| 1925.. | 7.40 | 7.21 | 9.65 | 12.32 | 11.98 | 11.23 | 13.05 | 14.10 | 12.41 | 9.27 | 8.56 | 7.08 | 10.36 |
| 1926.. | 8.50 | 9.18 | 10.72 | 11.56 | 12.63 | 14.95 | 15.89 | 16.59 | 11.57 | 10.39 | 7.68 | 5.90 | 11.30 |
| 1927.. | 8.31 | 7.60 | 12.53 | 10.47 | 12.85 | 14.07 | 13.33 | 15.15 | 12.85 | 9.41 | 8.80 | 6.41 | 10.98 |
| 1928.. | 10.61 | 10.80 | 12.05 | 13.97 | 11.98 | 14.05 | 14.90 | 17.84 | 13.42 | 10.65 | 6.24 | 6.38 | 11.91 |
| 1929.. | 7.52 | 8.04 | 11.33 | 12.94 | 13.45 | 13.86 | 13.18 | 16.11 | 13.14 | 7.33 | 6.76 | 7.16 | 10.90 |
| 1930.. | 9.41 | 8.77 | 9.32 | 12.15 | 12.01 | 11.97 | 11.38 | 11.46 | 10.55 | 7.12 | 6.52 | 5.93 | 9.72 |
| 1931.. | 6.36 | 6.47 | 8.35 | 11.73 | 13.03 | 12.26 | 12.95 | 13.73 | 10.56 | 8.87 | 7.16 | 6.99 | 9.87 |
| 1932.. | 7.49 | 6.92 | 8.99 | 9.47 | 9.73 | 10.63 | 12.07 | 12.85 | 10.70 | 5.91 | 6.02 | 6.24 | 8.92 |
| 1933.. | 7.00 | 6.14 | 8.89 | 10.28 | 12.60 | 11.62 | 11.63 | 12.80 | 11.00 | 8.24 | 6.47 | 5.36 | 9.34 |
| 1934.. | 8.10 | 6.56 | 9.21 | 11.25 | 11.62 | 11.83 | 13.33 | 12.95 | 10.65 | 8.06 | 7.03 | 6.45 | 9.75 |
| 1935.. | 5.55 | 8.04 | 9.15 | 10.24 | 12.19 | 14.56 | 15.47 | 14.02 | 12.20 | 8.75 | 8.01 | 7.99 | 10.51 |
| 1936.. | 7.77 | 8.40 | 12.49 | 12.39 | 14.06 | 12.88 | 13.76 | 15.28 | 13.85 | 10.67 | 8.37 | 6.76 | 11.39 |

Table 5—Mean Monthly Diurnal Ranges from 24-hour Readings of *H* at Agincourt

| | Jan. | Feb. | Mar. | Apl. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1899.. | 24.2 | 21.2 | 30.1 | 28.4 | 33.7 | 39.6 | 33.6 | 36.0 | 33.6 | 24.0 | 20.4 | 18.4 | 28.6 |
| 1900.. | 23.1 | 19.9 | 21.6 | 33.4 | 35.7 | 32.5 | 33.7 | 40.0 | 39.6 | 26.6 | 20.7 | 19.0 | 28.8 |
| 1901.. | 22.0 | 17.7 | 25.2 | 24.0 | 25.4 | 31.4 | 33.5 | 39.9 | 36.1 | 27.5 | 20.4 | 17.6 | 26.7 |
| 1902.. | 30.8 | 20.9 | 30.2 | 36.0 | 34.0 | 37.8 | 34.9 | 43.5 | 34.3 | 29.1 | 22.3 | 18.1 | 31.0 |
| 1903.. | 26.2 | 23.1 | 27.9 | 27.1 | 34.2 | 41.0 | 42.4 | 45.4 | 38.3 | 30.8 | 28.9 | 32.7 | 33.2 |
| 1904.. | 29.1 | 26.5 | 31.5 | 35.6 | 39.7 | 40.6 | 41.0 | 50.1 | 42.4 | 37.0 | 32.5 | 25.7 | 36.0 |
| 1905.. | 29.3 | 26.9 | 38.2 | 37.2 | 34.7 | 39.9 | 41.7 | 52.8 | 44.7 | 39.5 | 44.1 | 25.9 | 37.9 |
| 1906.. | 31.2 | 26.9 | 32.9 | 36.8 | 39.3 | 32.3 | 38.5 | 42.3 | 37.3 | 23.2 | 28.1 | 22.9 | 32.6 |
| 1907.. | 30.8 | 48.5 | 45.5 | 41.9 | 42.0 | 41.4 | 44.3 | 38.4 | 47.8 | 40.9 | 36.2 | 26.8 | 40.4 |
| 1908.. | 27.3 | 31.7 | 43.4 | 42.6 | 47.3 | 35.2 | 34.6 | 47.8 | 45.6 | 28.3 | 23.0 | 19.7 | 35.5 |
| 1909.. | 24.3 | 16.7 | 27.2 | 29.2 | 35.4 | 23.0 | 27.9 | 33.3 | 46.0 | 38.5 | 30.3 | 27.8 | 30.0 |
| 1910.. | 28.1 | 24.6 | 26.4 | 45.0 | 41.0 | 42.0 | 38.9 | 47.5 | 46.1 | 35.2 | 28.0 | 22.3 | 35.4 |
| 1911.. | 23.3 | 21.4 | 27.0 | 32.8 | 37.0 | 36.2 | 42.2 | 49.3 | 39.1 | 30.2 | 24.0 | 20.2 | 31.9 |
| 1912.. | 11.2 | 15.1 | 29.4 | 32.1 | 37.2 | 32.4 | 34.6 | 40.3 | 29.0 | 29.5 | 18.2 | 18.1 | 27.3 |
| 1913.. | 23.3 | 20.0 | 24.3 | 30.6 | 36.4 | 36.5 | 34.6 | 37.7 | 37.4 | 29.4 | 24.6 | 17.3 | 29.3 |
| 1914.. | 16.4 | 10.1 | 23.2 | 33.4 | 31.4 | 35.6 | 41.2 | 41.9 | 39.0 | 23.8 | 23.1 | 22.6 | 28.5 |
| 1915.. | 29.0 | 20.3 | 30.0 | 43.2 | 36.0 | 42.6 | 47.7 | 51.7 | 44.2 | 41.1 | 32.5 | 27.7 | 37.2 |
| 1916.. | 29.0 | 34.1 | 46.0 | 51.0 | 51.9 | 50.8 | 54.2 | 61.4 | 49.9 | 46.3 | 36.5 | 29.2 | 45.0 |
| 1917.. | 48.8 | 36.1 | 49.5 | 50.1 | 51.1 | 58.9 | 52.2 | 97.0 | 63.7 | 43.3 | 41.0 | 38.1 | 52.5 |
| 1918.. | 37.9 | 32.8 | 48.4 | 52.5 | 56.5 | 58.6 | 55.8 | 60.8 | 59.9 | 48.9 | 34.6 | 34.0 | 48.4 |
| 1919.. | 36.4 | 37.1 | 57.0 | 51.6 | 65.6 | 53.7 | 48.5 | 65.5 | 50.8 | 48.5 | 24.9 | 21.6 | 46.8 |
| 1920.. | 35.1 | 31.1 | 69.8 | 49.9 | 48.6 | 43.4 | 45.9 | 48.4 | 58.0 | 42.0 | 29.3 | 28.4 | 44.2 |
| 1921.. | 25.9 | 25.3 | 35.7 | 35.9 | 108.2 | 33.1 | 38.6 | 44.0 | 40.6 | 33.6 | 23.4 | 20.3 | 38.7 |
| 1922.. | 26.8 | 16.4 | 35.6 | 37.2 | 39.5 | 35.8 | 43.6 | 39.8 | 41.2 | 29.7 | 22.3 | 17.1 | 32.1 |
| 1923.. | 26.8 | 20.9 | 30.2 | 38.1 | 31.0 | 37.7 | 31.5 | 35.7 | 31.2 | 22.4 | 16.8 | 10.1 | 27.7 |
| 1924.. | 10.2 | 10.6 | 15.2 | 20.3 | 32.5 | 36.2 | 29.4 | 30.2 | 28.1 | 30.2 | 23.1 | 14.0 | 23.3 |
| 1925.. | 20.2 | 15.5 | 30.1 | 43.4 | 45.5 | 50.7 | 44.9 | 46.2 | 54.4 | 44.8 | 36.5 | 34.0 | 38.8 |
| 1926.. | 59.0 | 64.3 | 55.2 | 67.9 | 59.2 | 61.4 | 52.3 | 57.9 | 71.7 | 63.0 | 32.2 | 33.2 | 56.4 |
| 1927.. | 43.3 | 32.6 | 48.2 | 52.4 | 47.0 | 45.9 | 53.8 | 61.1 | 50.1 | 41.8 | 37.2 | 30.8 | 45.4 |
| 1928.. | 43.6 | 43.5 | 42.5 | 55.0 | 76.5 | 48.1 | 60.7 | 61.0 | 60.4 | 48.5 | 30.3 | 29.8 | 50.0 |
| 1929.. | 32.5 | 48.1 | 50.1 | 42.6 | 48.9 | 48.2 | 52.4 | 60.2 | 52.6 | 34.1 | 34.6 | 33.5 | 44.8 |
| 1930.. | 38.7 | 36.1 | 37.5 | 52.0 | 59.4 | 60.1 | 46.7 | 47.7 | 44.4 | 40.8 | 30.5 | 23.9 | 43.2 |
| 1931.. | 24.8 | 15.9 | 25.9 | 35.7 | 38.7 | 40.3 | 41.1 | 44.3 | 34.8 | 26.6 | 22.4 | 20.4 | 30.9 |
| 1932.. | 28.5 | 25.4 | 34.8 | 31.5 | 39.7 | 32.1 | 39.5 | 44.5 | 35.9 | 27.8 | 23.0 | 17.9 | 31.7 |
| 1933.. | 24.4 | 20.1 | 32.2 | 39.5 | 50.7 | 35.6 | 33.4 | 42.6 | 37.5 | 28.4 | 18.6 | 18.2 | 31.8 |
| 1934.. | 24.8 | 20.6 | 24.3 | 34.5 | 39.2 | 35.3 | 37.9 | 54.2 | 48.5 | 33.8 | 26.3 | 23.9 | 33.6 |
| 1935.. | 20.2 | 24.4 | 30.5 | 29.5 | 34.3 | 49.1 | 49.5 | 44.3 | 45.0 | 35.5 | 35.7 | 30.8 | 35.7 |
| 1936.. | 34.1 | 29.5 | 44.5 | 55.2 | 56.7 | 52.1 | 57.4 | 52.8 | 50.5 | 39.2 | 37.8 | 33.0 | 45.2 |

Table 6—Mean Monthly Diurnal Ranges from 24-hour Readings of *V* at Agincourt

| | Jan. | Feb. | Mar. | Apl. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1915.. | 8 | 8 | 13 | 16 | 19 | 28 | 13 | 15 | 21 | 24 | 32 | 6 | 16.9 |
| 1916.. | 9 | 7 | 25 | 24 | 25 | 18 | 24 | 27 | 30 | 28 | 16 | 9 | 20.2 |
| 1917.. | 17 | 8 | 8 | 15 | 20 | 21 | 25 | 50 | 24 | 23 | 10 | 20 | 20.1 |
| 1918.. | 9 | 18 | 14 | 30 | 30 | 25 | 29 | 37 | 43 | 38 | 23 | 26 | 26.8 |
| 1919.. | 16 | 17 | 35 | 29 | 57 | 19 | 18 | 34 | 39 | 38 | 9 | 19 | 27.5 |
| 1920.. | 7 | 9 | 21 | 25 | 19 | 14 | 17 | 17 | 37 | 15 | 12 | 10 | 16.9 |
| 1921.. | 4 | 4 | 10 | 17 | 57 | 10 | 12 | 14 | 15 | 25 | 14 | 8 | 15.8 |
| 1922.. | 8 | 11 | 24 | 31 | 21 | 19 | 24 | 21 | 32 | 16 | 4 | 4 | 17.9 |
| 1923.. | 3 | 8 | 7 | 7 | 8 | 13 | 6 | 7 | 13 | 14 | 4 | 4 | 7.8 |
| 1924.. | 4 | 3 | 6 | 6 | 17 | 14 | 9 | 7 | 11 | 8 | 4 | 3 | 7.7 |
| 1925.. | 4 | 4 | 4 | 7 | 14 | 24 | 11 | 17 | 21 | 16 | 10 | 10 | 11.8 |
| 1926.. | 27 | 20 | 22 | 33 | 29 | 24 | 16 | 12 | 37 | 24 | 7 | 4 | 21.4 |
| 1927.. | 4 | 5 | 21 | 17 | 18 | 12 | 22 | 33 | 21 | 22 | 4 | 6 | 15.2 |
| 1928.. | 3 | 4 | 4 | 7 | 24 | 18 | 22 | 17 | 14 | 16 | 10 | 5 | 12.0 |
| 1929.. | 3 | 13 | 21 | 7 | 15 | 17 | 25 | 19 | 24 | 18 | 23 | 15 | 16.7 |
| 1930.. | 8 | 14 | 20 | 38 | 51 | 68 | 33 | 42 | 45 | 36 | 12 | 10 | 31.4 |
| 1931.. | 7 | 10 | 7 | 8 | 14 | 11 | 9 | 15 | 13 | 21 | 9 | 7 | 10.9 |
| 1932.. | 7 | 9 | 18 | 25 | 32 | 7 | 10 | 17 | 14 | 8 | 6 | 5 | 13.2 |
| 1933.. | 4 | 4 | 6 | 11 | 10 | 8 | 6 | 6 | 11 | 6 | 3 | 4 | 6.6 |
| 1934.. | 3 | 7 | 17 | 10 | 9 | 9 | 7 | 14 | 12 | 9 | 7 | 13 | 9.8 |
| 1935.. | 12 | 16 | 14 | 16 | 16 | 17 | 15 | 7 | 35 | 25 | 14 | 16 | 16.9 |
| 1936.. | 15 | 16 | 24 | 55 | 33 | 44 | 24 | 12 | 5 | 25 | 18 | 12 | 23.6 |

Table 7—Observed and Computed Mean Yearly Diurnal Variation of the Magnetic Elements at Agincourt

| | *D* Variation | | | *H* Variation | | | *V* Variation | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Ob. | Com. | O-C | Ob. | Com. | O-C | Ob. | Com. | O-C |
| | ′ | ′ | ′ | γ | γ | γ | γ | γ | γ |
| 1899... | 8.56 | 8.97 | −0.41 | 28.6 | 30.6 | − 2.0 | | | |
| 1900... | 8.47 | 8.87 | −0.40 | 28.8 | 29.9 | −1.1 | | | |
| 1901... | 8.06 | 8.61 | −0.55 | 26.7 | 28.2 | −1.5 | | | |
| 1902... | 8.56 | 8.70 | −0.14 | 31.0 | 28.8 | +2.2 | | | |
| 1903... | 8.83 | 9.45 | −0.62 | 33.2 | 33.7 | −0.5 | | | |
| 1904... | 9.45 | 10.14 | −0.69 | 36.0 | 38.2 | −2.2 | | | |
| 1905... | 9.39 | 10.98 | −1.59 | 37.9 | 43.7 | −5.8 | | | |
| 1906... | 9.01 | 10.60 | −1.51 | 32.6 | 41.2 | −8.6 | | | |
| 1907... | 9.42 | 10.92 | −1.50 | 40.4 | 43.3 | −2.9 | | | |
| 1908... | 9.65 | 10.39 | −0.74 | 35.5 | 39.9 | −4.4 | | | |
| 1909... | 9.25 | 10.21 | −0.96 | 30.0 | 38.7 | −8.7 | | | |
| 1910... | 9.44 | 9.22 | +0.22 | 35.4 | 32.2 | +3.2 | | | |
| 1911... | 8.73 | 8.72 | +0.01 | 31.9 | 29.0 | +2.9 | | | |
| 1912... | 8.53 | 8.64 | −0.11 | 27.3 | 28.4 | −1.1 | | | |
| 1913... | 8.83 | 8.55 | +0.28 | 29.3 | 27.9 | +1.4 | | | |
| 1914... | 8.64 | 8.87 | −0.23 | 28.5 | 29.9 | −1.4 | | | |
| 1915... | 10.17 | 10.35 | −0.18 | 37.2 | 39.6 | −2.4 | 16.9 | 17.4 | − 0.5 |
| 1916... | 10.79 | 10.73 | +0.06 | 45.0 | 42.1 | +2.9 | 20.2 | 19.7 | + 0.5 |
| 1917... | 12.41 | 12.55 | −0.14 | 52.5 | 54.1 | −1.6 | 20.1 | 30.9 | −10.8 |
| 1918... | 11.90 | 11.64 | +0.26 | 48.4 | 48.1 | +0.3 | 26.8 | 25.3 | + 1.5 |
| 1919... | 11.42 | 10.98 | +0.44 | 46.8 | 43.7 | +3.1 | 27.5 | 21.3 | + 6.2 |
| 1920... | 11.00 | 9.97 | +1.03 | 44.2 | 37.1 | +7.1 | 16.9 | 15.0 | + 1.9 |
| 1921... | 10.36 | 9.52 | +0.84 | 38.7 | 34.2 | +4.5 | 15.8 | 12.3 | + 3.5 |
| 1922... | 9.01 | 9.05 | −0.04 | 32.1 | 31.1 | +1.0 | 17.9 | 9.4 | + 8.5 |
| 1923... | 8.78 | 8.73 | +0.05 | 27.7 | 29.0 | −1.3 | 7.8 | 7.4 | + 0.4 |
| 1924... | 9.42 | 9.15 | +0.27 | 23.3 | 31.8 | −8.5 | 7.7 | 10.0 | − 2.3 |
| 1925... | 10.36 | 10.23 | +0.13 | 38.8 | 38.8 | 0.0 | 11.8 | 16.6 | − 4.8 |
| 1926... | 11.30 | 10.99 | +0.31 | 56.4 | 43.8 | +12.6 | 21.4 | 21.3 | + 0.1 |
| 1927... | 10.98 | 11.19 | −0.21 | 45.4 | 45.1 | +0.3 | 15.2 | 22.6 | − 7.4 |
| 1928... | 11.91 | 11.53 | +0.38 | 50.0 | 47.3 | +2.7 | 12.0 | 24.7 | −12.7 |
| 1929... | 10.90 | 11.04 | −0.14 | 44.8 | 44.1 | +0.7 | 16.7 | 21.6 | − 4.9 |
| 1930... | 9.72 | 9.89 | −0.17 | 43.2 | 36.6 | +6.6 | 31.4 | 14.6 | +16.8 |
| 1931... | 9.87 | 9.33 | +0.54 | 30.9 | 32.9 | −2.0 | 10.9 | 11.1 | − 0.2 |
| 1932... | 8.92 | 8.93 | −0.01 | 31.7 | 30.3 | +1.4 | 13.2 | 8.7 | + 4.5 |
| 1933... | 9.34 | 8.72 | +0.62 | 31.8 | 29.0 | +2.8 | 6.6 | 7.4 | − 0.8 |
| 1934... | 9.75 | 8.84 | +0.91 | 33.6 | 29.7 | +3.9 | 9.8 | 8.1 | + 1.7 |
| 1935... | 10.51 | 9.91 | +0.60 | 35.7 | 36.7 | −1.0 | 16.9 | 12.3 | + 4.6 |
| 1936... | 11.39 | 11.64 | −0.25 | 45.2 | 48.0 | −2.8 | 23.6 | 25.3 | − 1.7 |

**Table 8—Eleven-year Means and Annual Variation of Diurnal Range at Agincourt**

| | | Jan. | Feb. | Mar. | Apl. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D | 1900 to 1911 | ′ 6.32 | ′ 6.53 | ′ 8.90 | ′ 10.09 | ′ 10.44 | ′ 10.99 | ′ 11.47 | ′ 13.20 | ′ 11.09 | ′ 7.65 | ′ 6.45 | ′ 5.47 | ′ |
| | 1911 to 1921 | 7.11 | 7.08 | 10.22 | 11.61 | 12.13 | 12.86 | 13.31 | 14.53 | 12.24 | 8.72 | 7.23 | 5.98 | |
| | 1922 to 1932 | 7.81 | 7.61 | 9.98 | 11.46 | 11.91 | 12.58 | 12.85 | 14.05 | 11.57 | 8.24 | 7.10 | 6.09 | |
| | 1900 to 1932 | 7.08 | 7.07 | 9.70 | 11.05 | 11.49 | 12.14 | 12.54 | 13.93 | 11.63 | 8.20 | 6.93 | 5.85 | |
| | 3 max. spot years | 8.76 | 8.98 | 12.10 | 12.40 | 12.48 | 13.68 | 13.65 | 16.17 | 12.80 | 9.73 | 7.44 | 6.32 | 1905 17 28 |
| | 3 min. spot years | 6.45 | 5.96 | 8.57 | 10.08 | 10.97 | 11.79 | 10.37 | 12.17 | 10.68 | 6.87 | 6.49 | 4.29 | 1902 13 23 |
| H | 1900 to 1910 | γ 27.5 | γ 25.8 | γ 31.8 | γ 35.3 | γ 37.2 | γ 36.1 | γ 37.4 | γ 43.7 | γ 41.7 | γ 32.4 | γ 28.6 | γ 33.4 | γ |
| | 1911 to 1921 | 28.8 | 25.8 | 40.0 | 42.1 | 50.9 | 43.8 | 45.0 | 54.4 | 46.5 | 37.9 | 28.4 | 25.2 | |
| | 1922 to 1932 | 32.2 | 29.9 | 36.8 | 43.3 | 47.1 | 45.1 | 45.2 | 48.1 | 45.9 | 37.2 | 28.1 | 22.2 | |
| | 1900 to 1932 | 29.5 | 27.2 | 36.2 | 40.2 | 45.1 | 41.7 | 42.5 | 48.7 | 44.7 | 35.8 | 28.4 | 26.9 | |
| | 3 max. spot years | 00.6 | 35.5 | 43.4 | 47.4 | 54.1 | 47.0 | 51.5 | 70.3 | 56.3 | 43.8 | 38.5 | 31.3 | 1905 17 28 |
| | 3 min. spot years | 27.0 | 20.6 | 28.2 | 34.9 | 33.8 | 37.3 | 33.7 | 39.0 | 34.3 | 27.0 | 21.2 | 15.2 | 1902 13 23 |
| V | 1922 to 1932 | 7.1 | 9.2 | 14.0 | 16.9 | 22.1 | 20.6 | 17.0 | 18.8 | 22.3 | 18.1 | 8.5 | 6.6 | |
| | 3 max. spot years | 20.0 | 14.7 | 18.0 | 34.3 | 27.3 | 29.7 | 21.7 | 24.7 | 22.0 | 24.0 | 11.7 | 12.0 | 1917 26 36 |
| | 2 min. spot years | 3.5 | 6.0 | 6.5 | 9.0 | 9.0 | 10.5 | 6.0 | 6.5 | 12.0 | 10.0 | 3.5 | 4.0 | 1923 1933 |

# COSMIC TERRESTRIAL RELATIONSHIPS*

## A Report to the American Geophysical Union

So many problems concerning the nature and structure of our earth cross the conventional compartments into which technical work has become segregated that even such divergent fields as astronomy, geology, meteorology, and engineering may be expected to yield invaluable elements in a comprehensive geophysical approach to earth science. Excellent examples of coordinated interests in geophysics requiring the closest cooperation are the Special Committees of the American Geophysical Union—one on the Geophysical and Geological Study of Continents and the other on the Geophysical and Geological Study of Oceanic Basins.

It is because of this fact that in canvassing every avenue of approach to certain problems encountered by these committees that a third Special Committee of the American Geophysical Union has recently been formed. It is hoped that an investigation of such material as now exists or may yet be acquired will add information concerning the part that extra-terrestrial forces may play in geophysical phenomena. There is much evidence of changes taking place in the earth and its atmosphere for which satisfactory explanations do not appear to be forthcoming in the study of the earth alone.

This Special Committee on Cosmic Terrestrial Relationships is informed that its particular function will be to investigate all possible effects of extra-terrestrial bodies on the lithosphere, hydrosphere, and atmosphere of the earth by (1) attempting a comprehensive evaluation of observational data and methods, and (2) giving consideration to both the methods and the means of acquiring further experimental and observational data.

*Editorial Note.—The American Geophysical Union is a body operating under the U.S. National Academy of Sciences. The Union appointed a committee of twenty members, Harlan T. Stetson being chairman, to summarize the results of research into the nature and structure of the earth obtained in various branches of science. This first Report appears in the Transactions of the American Geophysical Union for 1939, published by the National Research Council, Washington, D.C.

Since this Committee was especially appointed for the purpose of supplementing the Committee on the Geophysical and Geological Study of Oceanic Basins and the Special Committee on the Geophysical and Geological Study of Continents, it has been requested that, at least at the outset, our Committee devote its attention to such specific data as may bear upon the question of the origin and detecting of movements of the crustal structure where extra-terrestrial factors or observations may be concerned.

Whatever success the Committee may hope to achieve must depend not only upon extensive cooperation but upon the approach to its problems without prejudice to any theory or anticipating verification of any preconceived interpretations.

As the nature of the basement-complex underlying continents and oceans and the question of translatory movements in the earth's crust are of vital consequence in structural geology, geophysics in its broader aspects should find every available source of data that may be helpful in extending our information in these directions. The accumulating evidence for continued, yet intermittent, migrations of land-masses irrespective of the amount, and the existence of certain unaccountable variations in geographic coordinates determined from astronomical observations suggest that serious consideration should be given to any interrelation that may appear to exist. Geologists have long sought for astronomical evidence for shifts in land-masses. On this subject observations have been conflicting and disappointing. An examination of systematic distributions, in which "errors of observation" are generally regarded as inevitable, may add light to the problems or at least suggest certain directions in which increased precision may be obtained. It seems desirable, before discussing existing data relative to variations in geographic coordinates and the degree of reliability which may be placed upon them, to summarize from the point of view of the structural geologist the evidence that the earth itself affords regarding crustal movements. Professor W. T. Thom, Jr., Chairman of the Special Committee on the Geophysical and Geological Study of Continents, has furnished your Committee with valuable material which is summarized below.

## Geological Evidence for Crustal Movements

(1) Geologic study of the crustal structure of the earth gives evidence for some force or agency causing crustal deformation that has been operative since pre-Cambrian times. The indication of recurrent mountain-building episodes suggests that the results of such forces as have been operative have been intermittent, migratory, and marked with more or less rhythm.

(2) Observations of fracturing, thrust-faulting, and folding which make up the structural picture so familiar to geologists indicate that such superficial deformations involve a near-surface veneer of rock from 15 to 70 km. in thickness.

(3) This veneer, which we may call the crust of the earth, is relatively rigid and strong as compared to the asthenosphere or zone of isostatic compensation that appears to underlie the crust itself.

(4) The surface-feature makes it clear that the crust includes certain more rigid "shield"-areas. These areas, chiefly granitic in the case of continents, are conspicuous in the following areas: Canadian regions surrounding, and south of, Hudson Bay; South America to the east and southeast of the Andes; Africa south of the Atlas Mountains; Arabia and India; the Scandinavian and the Russian platform-regions north of the Alps and northeast of the Carpathians and west of the Urals; the Angara shield of north-central Siberia; a sub-shield in the part of China lying east of Tibet; the Australasian shield south and southeast of the East Indian Island-Arc; and Antarctica. The probability seems great that suboceanic "shield"-areas also exist, but positive evidence of this can only come from more adequate exploration of the oceanic bottoms.

(5) Between these shields, that is, peripheral to the continental shield-areas, belts have developed from time to time in which seismic disturbances and vulcanism have accompanied or preceded the crowding together of these strips of crust, or orogenic zones. Crumpling of an orogenic belt produces an arcuate mountain range, or island-arc, plus a fore-deep or geosyncline. With the development of such a fore-deep, it tends to become filled with clastic materials, eroded from the contiguous hinterland-uplift or mountain range; and with the crowding of this range against the trough-fill, the fill becomes first crumpled and then apparently shoved up on the margin of the shield in a series of folds and overthrusts.

(6) While there definitely have been recurrent episodes of mountain-building, the cycle can hardly be called rhythmic or periodic in any exact sense. But it would appear that recurrences of mountain-building may have taken place at fairly regular intervals of 30 to 40 million years. Within each major mountain-building episode there are evident many minor rhythms or cycles of elevations of the hinterland, accompanied by sympathetic depression in the trough or basin of down-folding, and an obvious crowding of the hinterland towards the trough or "orogen" thus developed. The time required for a mountain-building episode—a million years or so—is relatively brief as compared to the interval of 30 to 40 million years between orogenic maxima. Sub-rhythms of the major episodes have apparently occurred at intervals of perhaps 10,000 to 100,000 years. Still shorter intervals between earth-movements are recognized by periods of marked seismic disturbances at intervals as brief as tens or hundreds of years. Such recurrences of activity are suggestive of the relief of accumulated stress which may be due to the persistence of small forces acting continuously or intermittently in a given direction.

The crustal shortening, as measured by the horizontal overthrusting occurring within one major mountain-building episode, may amount to as much as 25 to 50 miles as a minimum in a given orogenic period. Some authorities, not satisfied with so conservative a statement, would claim a crustal shortening measured in hundreds rather than tens of miles in a given period.

While translatory movements have been taking place, evidence abounds for vertical changes. Changes of level now going on are of course most in evidence in regions of instability. Every marked seismic catastrophe affords an exhibition of both lateral and vertical displacements. Measurable changes in level, however, take place in certain regions even when not accompanied by conspicuous earthquake-activity. A Japanese survey in the vicinity of Ito has revealed changes of level of five to eight inches over the interval from 1930 to 1933. Researches with the new form of gravimeter recently developed at the Gulf Laboratories have demonstrated earth-tides with an apparent rise and fall of the order of a foot during the lunar day. Removal of the uncertainty in the amplitude involved awaits a more complete calibration of the gravimeter.

With the accumulating evidence for mobility in the earth's crust, it is not surprising that structural geology turns to geophysics and astronomy for inquiry as to the possibility of extra-terrestrial origin of forces that may be operative, or for information from geodetic measurements as to the magnitude and direction of such movements as may be detected from astronomical observation.

Tidal forces exerted by the moon and sun offer, so far as is known, the only appreciable potentials of extra-terrestrial origin that can enter into the problem. Such forces at best are so small compared with the forces that have been at work in mountain-building and crustal deformation in geological time that, at least thus far, little encouragement has been found from the examination of such disturbing factors from outside the earth. The fact that earth-tides do exist and that accumulating stresses may ultimately play a part in earth-movements, however, must continuously be kept in mind. A recent survey of earthquake-frequencies as related to the lunar hour-angle offers some little support for the deductions that accumulating tidal stresses may at least be a help in the precipitation of seismic events, especially where earthquakes of deep focus are concerned. (See [1] of "References" at end of report).

## Astronomical Evidence for Variation in Geographic Coordinates

Reflecting upon the above facts, geodesists and astronomers naturally have become interested in intercomparing observations of position for any given station after lapsed intervals to determine what, if any, migratory movements of the land may have taken place between periods of observation. The controversy over the Wegener hypothesis of continental drift at least served as a stimulus to astronomical investigations of change in position. Old and new surveys were intercompared—latitudes and longitudes of known points were reobserved, often with conflicting results but with no definite assurance of land-migrations of the order of magnitude demanded by the proponents of the Wegener hypothesis [2]. With the passing of the more heated stage of the controversy, there is time to reexamine astronomical data without prejudice as to any anticipated results.

Considering all the evidence for crustal movement which geology has gathered, it is perhaps somewhat surprising that the intercomparison of astronomical determinations of latitude and longitude over a period of years has revealed so little evidence for some change that would not fall within the range of the inevitable errors of observation. A study of these observational errors, on the other hand, may yet reveal sources of systematic differences which may give some clue to their origin. With the best of modern equipment, a series of astronomical observations at a given station should locate the geographical coordinates of the point occupied with an accuracy of less than half a metre in latitude and one to two metres in longitude—an ideal of precision seldom attained in practice due to atmospheric refraction and turbulence that disturbs the light from the star under observation. Nevertheless, in averaging large numbers of observations made under all sorts of meteorological conditions, non-periodic differences have a way of eliminating themselves. The now well-recognized motion of the earth's pole of rotation about its pole-of-figure was brought to light in the latter part of the nineteenth century by periodic variations of latitude amounting to but a few metres as measured on the great-circle arc. The length of this period of latitude-variation, marked by Chandler as 428 days, was so discordant with the theoretical period of 310 days predicted by Euler for a rigid body that the discrepancy made possible an evaluation of the deformation of the earth's figure due to the changed accelerations involved. The establishment in 1899 of a series of latitude-stations on the parallel of 39° 08′ by the International Geodetic Association made possible the continued study of the wandering of the terrestrial pole and at the same time revealed variations still to be accounted for that may yield information of geophysical interest.

A study of these residuals in latitude-variations after the known motion of the pole has been removed suggests certain dependence of these variations upon the moon's position which would appear to link the importance of such astronomical observations to the geophysical problem of earth-tides—a subject that has occupied a Commission of the International Union of which Dr. Lambert, a member of our Special Committee, has proved an able reporter [3]. Certain inconsistencies and changes of phase in the behaviour of latitude-residuals, depending upon the region of the globe and the

period over which the observations have been examined, complicate the problem but may suggest that we shall have to entertain the possibility that irregular and regional oscillatory movements take place with migratory tendencies over longer periods of time.

In the reductions of the observations of the International Latitude Service of 1923 to 1931, Professor Kimura, former chairman of the Commission, pointed out that the results from the latitude-station at Mizusawa were inconsistent with those derived from the other stations on the same parallel by an amount which would be reconciled were one to suppose that the Japanese observatory had drifted southward by about three metres from the position occupied ten years before [4]. Dr. Lambert believes, however, that a real motion of the pole, combined with a systematic error in the proper motions of the stars, provides an equally good explanation. In this case, the latitude of the Russian station at Charjui appears out of line rather than that of Mizusawa. Dr. Lambert would be inclined to attribute the discrepancy to uncertainty in observations.

While Talcott's method of observation, utilizing the zenith-telescope, offers the highest degree of precision and is that in use at all the international latitude-stations, it is unfortunate that it requires an accurate knowledge of the declination of the stars. The fact that each station utilizes the same stars for observations supposedly makes possible an evaluation of the corrections to the declinations used if such are needed. It has been customary, therefore, to correct star-positions by the results determined from each period of reductions of latitude-observations. This procedure, however, is somewhat unfortunate, since were there any general migration of all stations to or from the equator, such a movement would be completely masked by this process of correction. Comparisons of apparent changes in the declinations of the latitude-stars with their proper motions derived from other astronomical sources, afford a means of ultimately solving the dilemma. There is need for still greater precision in the determination of latitude and a continued examination of the sources of error that may underlie individual discrepancies.

A systematic variation in the observed latitude at the Greenwich Observatory has shown a marked dependence upon the direction and velocity of the wind at the time the star-observations are made,

the residuals being plus for north and northeasterly winds and minus for south and southwesterly winds [5]. With the thought that direction and velocity of wind are the indexes to the potential gradient, Professor Brooks has investigated the lateral refraction that may result with the approach and recession of cold fronts in the vicinity of the British Isles. While the magnitude of the refraction that could be thus introduced, he assures us, cannot be greater than one-tenth of a second of arc, even this is a quantity of significance in dealing with the variations observed. It is believed that a comparison of pressure-disturbances over the North Atlantic corresponding to the times of latitude-observations may yield sources of information of help in this connection.

While this report is being written, there has appeared a communication to the Royal Astronomical Society from H. Spencer Jones, Astronomer Royal, concerning the investigation of the variations in latitude at the Greenwich Observatory [5a]. In the analysis of five years' observations with the Cookson floating telescope, it is believed corrections have been made for seasonal variations and wind-effect. A semidiurnal lunar tidal component in the variations has been derived which, when augmented by a correction-factor due to tides in the River Thames, agrees remarkably with values predicted by theory. It should be noted that in treating the observations, corresponding groups of data 12 hours apart were purposely combined in forming the means, thus tacitly assuming a degree of symmetry in the semidiurnal earth-tide.

It is perhaps unfortunate from the point of view of the study of the wandering of the terrestrial pole that three of the four international latitude-stations now in operation are located in regions of more or less geological and meteorological instability. The establishing of another chain of latitude-stations in a subtropical zone, choosing locations of greater geological and meteorological equilibrium, may be desirable. An intercomparison of the results on two different parallels would be of interest. Meanwhile, it is fortunate that latitude-stations in the southern hemisphere have been established which in a few years should yield results of importance.

## Variations in Longitude

The observational errors encountered in the determination of latitude pertain also to the difference of longitude with the additional difficulty incident to maintaining clocks at constant rates and transmitting time-signals betwen the two points whose difference in longitude is being measured. The probable error resulting in the value of longitude from a series of observations is a matter of thousandths of seconds of time or the order of $\pm 0.007$ second.

Studies of longitude-differences from time-comparisons, however, yield surprising results. In 1931, for example, a redetermination of the longitude between the Argentine National Observatory at Cordoba and the Royal Observatory at Greenwich yielded a value one whole second less than that made under the direction of Dr. Gould in 1871 [6]. Dr. Gould's determination rested upon two very careful longitude-determinations by the United States Navy astronomical expeditions which derived independently the longitude of Buenos Aires from Greenwich and that of Valparaiso from Washington. The two determinations made by way of the Atlantic and the Pacific coast, respectively, gave an agreement within 0.05 second, or a linear uncertainty of about 16 metres.

In the determination of 1931 the time-signals were exchanged by radio in place of cable. The probable error from the 35 nights' observations gave an uncertainty of but 0.007 second, yet the results of the longitude in 1931 differed from that of 1871 by 1.11 seconds, corresponding to a linear distance of 400 metres, an unthinkable difference to be charged to the account of observational errors. Commenting upon the results, Zimmer of the Cordoba Observatory states:

> Cordoba with respect to Valparaiso and Buenos Aires seems to have been well determined as a comparison of the above values shows, thus clearly demonstrating that whatever error there is in the longitude of Cordoba came in through erroneous determinations of Valparaiso and Buenos Aires. The remarkable thing about it is that the two independent determinations, such as those made by Green and Davis, should be in such complete accord and yet both be wrong by a whole second. We have to assume that those two determinations were in error by at least a round second, since it is impossible to imagine at the present time any such continental drift and especially so since the shift, if there has been any at all, would have had to take place in the opposite direction to that predicted by the theory of Wegener and others.

It is perhaps unfortunate that Zimmer bases his interpretations upon the failure of the resulting difference to agree with the Wegener hypothesis.

While *errare est humanum*, it seems unthinkable to those acquainted with the details of a longitude-campaign that an error of a whole second should have escaped the well-trained observers of 1871. It seems equally unthinkable that the two determinations, one by way of the Pacific and the other by way of the Atlantic, should have yielded results consistent within 0.05 second, and yet conceal a mistake of 20 times this amount. Making due allowances for slight differences which may have resulted in the comparison of signals by cable in the earlier series as compared with radio in the latter series, is it possible that some of the differences involved may be charged to the geological side of the ledger?

One other outstanding discrepancy in longitude-determinations may be mentioned briefly. It is that involving the position of Sabin Island determined by Jelstrup in 1932 [8] as compared with the position found by Börgen and Copeland in 1869 and 1870 [9]. Jelstrup's new determination, using the identical pier employed in 1870, gave the position 615 metres west of that found from the earlier measures. While Börgen and Copeland did not have the advantage of cable and radio and were obliged to depend upon the more or less unsatisfactory method of lunar observations for determining Greenwich time, examination of the original publications show that the longitude that these observers derived from 16 lunar culminations agreed within 1.5 seconds of their determination based upon four star-occultations. The probable error of the mean of each of the two independent determinations was $\pm 1.1$ seconds. This would indicate that the results of Börgen and Copeland were as satisfactory as the circumstances of that time would allow. Jelstrup, using radio communication for determination of Greenwich time in 1932, derived a value for longitude nearly five whole seconds greater than the results of Börgen and Copeland in 1870.

It would appear from the internal evidence of the observations themselves that Jelstrup's observations could not be wrong by much more than 20 metres while the uncertainty of the observations in 1870 was about four times this amount. Nevertheless, if we allow for the worst possible combination of these estimated errors, it

would appear that the results in 1932 indicate a longitude farther west by 250 metres from that indicated by the earlier observations.

It should be emphasized that at the same time the latitude resulting from the observations in 1932 was less than that of the observations in 1870 by six seconds of arc, corresponding to a linear distance of 200 metres. Whatever doubt may be cast upon the interpretation of the longitude-differences, it should be emphasized that the latitude-determinations were entirely independent of exchange of time-signals and that the order of accuracy attainable for latitude-determinations in 1870 was nearly as great as in 1932.

The above two instances have been mentioned not in support of any theory or with any attempt to establish continental drift, but are mentioned as examples of the type of facts which must be met and evaluated without prejudice from astronomers who would like their observatories to stay put, or from certain geologists who would like to have the continents moved.

A study of the intercomparison of radio time-signals exchanged across the Atlantic over a period of five years (1929-1934) has revealed variations in the differences much larger than apparently can be accounted for on the basis of observational errors.

The more or less periodic nature of the discrepancies in the determination of time on the two sides of the Atlantic through the examination of radio time-signals, which often occur with more or less rhythm, suggested to Loomis and Stetson a systematic search for any possible correlation for these variations with the hour-angle and declination of the moon [10]. The results at first yielded surprising changes of the order of 0.05 second that appeared to depend both upon the lunar hour-angle and declination. Characteristics of the resulting curves suggested earth-tidal origin, yet the amplitude appeared too great to be consistent with the theory. Kawasaki has shown [11] that the reversal in phase which might have been attributed to the changing declination of the moon would be equally well accounted for by an annual term of unknown origin. More recently Professor Schlesinger, utilizing our derived data, has shown that at least the major variations attributable to the declination alone could be satisfied by the introduction of a correction for longitude dependent upon the change of the pole of rotation with respect to the pole of figure [12].

It should be noted that investigations at the Tokyo Observatory have confirmed in a large measure the variations in terrestrial longitude discussed above and bring to light the decrement in amplitude of the measured variations during the years 1934 and 1935 [13]. Recent unpublished investigations by your Chairman show for the earlier years a semidiurnal residual apparently still correlatable with the lunar hour-angle, a variation which practically vanished in 1934 at the time when the two components of the polar motion brought the pole to its mean position.

It has been most unfortunate that since June 1934 the daily intercomparison of transatlantic time-signals between our own Naval Observatory and the Observatory at Greenwich has been interrupted on account of the removal of the 17.6-kc. frequency time-signal due to changes in the transmitting station at Annapolis. Through the cooperation of the British Admiralty a short-wave receiver has been installed at the Greenwich Observatory, and, beginning with January 1, 1939, the Washington signal (NAA) at $9^h$ GT has been received on 9425-kc. frequency and corrections to these signals have been published in the Admiralty Notices since January 1, 1939. Since, however, the short waves are uncertain during the summer but the low-frequency waves are propagated with reasonable velocity at all seasons and are less subject to ionospheric disturbances, your Committee has urged the reinstatement of the 17.6-kc. frequency. As this report was being transmitted to the Union at its twentieth annual meeting, Captain Hellweg, Superintendent of the Naval Observatory and member of our Committee, was happy to announce that through the cooperation of the Navy the noon time-signals (GMT. $17^h$) on 17.6-kc. will be reinstated immediately. Plans are now being made through the technical assistance of Dr. Ewing for providing oscillograph recording that will make possible the reception of time-signals at the Naval Observatory with a precision of the order of 0.001 second.

Since the determination of any variations in longitude, real or apparent, must rest upon the fundamental assumption that radio waves are propagated at the same velocity travelling from east to west as from west to east, a project has been submitted and approved by the Planning and Project Committee of our Union for conducting an experiment for the purpose of testing the assumed invariability

of velocity of propagation from west to east as compared with the east-to-west direction across the earth's magnetic field.

The precision obtained by Ewing [14] in determining gravity at sea, using as the timing mechanism of the pendulum-apparatus a crystal chronometer loaned by the Bell Telephone Laboratories to the American Geophysical Union, led us to believe that this timepiece could be profitably employed in testing the fundamental assumption relative to the propagation of time-signals by radio. This project proposes to transport by airplane a crystal chronometer, capable of maintaing a rate uniform within 0.001 second per day, from Langley Field near the Naval Observatory in Washington to a point in the interior of the country some 2000 miles west of Washington, the plane to fly at a speed of approximately 200 miles an hour and to record aboard the plane the signals from Washington as received by the crystal chronometer. Similarly, signals from the moving chronometer could be recorded at the Naval Observatory. Since these time-signals will be received hourly, there should be an apparent cumulative lag in the reception-times of about 0.001 second for each successive hour of flight. Assuming that a continuous flight of seven hours can be made before the termination of the journey, there will be an accumulated lag of 0.007 second by the time the signals are received over the 1400-mile base-line—a time considerably in excess of any expected error of which the crystal chronometer is capable.

In a return journey immediately following, the 0.007-second lag should be reduced by approximately 0.001 second per hour until arrival of the plane again at Langley Field near Washington. The crystal chronometer originally synchronized with the crystal clock at the Naval Observatory should again appear to be in complete synchronization at the end of the experiment. If the experiment performed as just outlined yields consistent results, we should, we believe, have sufficiently verified the fundamental assumption as to the constancy of east-to-west and west-to-east transmission of wireless waves, thus removing all doubt as to the trustworthiness of data depending upon time-signal communication. Should there appear a difference in the lag of the reception of the signals in the return journey from corresponding signals received on the outgoing trip, we should probably have made an even more significant contribution to science.

Detailed plans for the location of a plane and personnel have been completed during the past year but await authorization from the War Department for the utilization of the necessary flying equipment. In accordance with the present policies of utilizing military equipment exclusively for military purposes, the War Department has thus far continued to decline our requests. Search will evidently have to be made for other sources of airway-equipment. It is hoped that, after the crystal chronometer now on loan to the Dutch Gravity Expedition is again returned to the Union, the arrangements may be completed for carrying out so important an experiment to test the validity of a fundamental postulate.

The evidence from a close examination of existing data from previous longitude-campaigns have brought to light apparent variations in the group-velocity of time-signal radio waves that appear to depend upon the geographic or geomagnetic latitude [15]. Since it is evident from such a study that one may no longer assume that radio waves travel with the velocity of light over the great-circle route connecting the two points in question, consideration will have to be given in future longitude-determinations to the location of radio equipment coincident with the station utilized for the star-observations.

A study of the recent investigations by Stoyko and Jouaust reported at the Stockholm Assembly of the International Union of Geodesy and Geophysics leads to the conclusion that the authors believe that a periodical variation in longitude may be easily explained by the pulsation of the earth's crust without recourse to the displacement of continents [16].

An important contribution by Sollenberger and Clemence has just been communicated in advance of publication to our Committee relative to the detection of any lunar effect in time-observations made at the Naval Observatory with the photographic zenith-tube. A careful analysis by them reveals no variation in time-determinations correlatable with the moon from observations from March, 1934, to February, 1939, other than what could be accounted for by theory. If the apparent variations in longitude from time-comparisons on the two sides of the Atlantic were due to earth-tidal deformation, one would expect that the results at each of the two observatories concerned would show a certain dependence of its meridian

upon the hour-angle of the moon. However, since complete data for intercomparison of the transatlantic time-signals have not been available since the discontinuance of the 17-kc. transmission in 1934, there is no way of comparing results across the Atlantic for the same period for which the observations at Washington have been analyzed.

In addition to the investigations already mentioned which have been completed or initiated, your Committee, in cooperation with the Geological Society of America and the two other Special Committees of the Union, participated in a symposium at the winter meeting of the American Association for the Advancement of Science at Richmond. Certain matters mentioned in this report were presented in connection with the discussion of problems reviewed by the Special Commitee on Continents and that on Oceanic Basins. It is obvious that the active work of the two other Special Committees in pursuing researches on gravity and seismology on land and at sea may bring to light regional data of vital consequence to the study of crustal movements. It is hoped that the Special Committee on Cosmic Terrestrial Relationships, from the continuance of the investigations above-mentioned, may add its contributions to the fundamental geophysical studies in which the Union is engaged.

The nature of the work of this Special Committee naturally differs somewhat from that of the other two Special Committees in that a large amount of study of fundamental questions is involved as well as the initiation of certain experiments and observations. This first report must therefore, in a sense, remain preliminary.

There are many other problems involving important cosmic terrestrial relationships already recognized which in due course may well receive the attention of your Special Committee. It is your Committee's opinion, however, that for the present a continuation of the study of the problems above-outlined, involving the question of variations in geographic coordinates, the exchange of time-signals, and a study of the peculiarities of radio propagation so important in the determination of longitude, should occupy its principal attention.

The Committee will take this occasion to express its appreciation for the cooperation which has been received from Government agencies and scientific experts who have interested themselves in the difficult problems whose investigation has been undertaken.

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Massachusetts Institute of Technology,
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# ASTRONOMY AS A HOBBY*

By H. Boyd Brydon

IF you will look at the southern sky during the late evening, you will see, rather low down, two bright red stars; one a little west of south, the other about south-east.

Strictly speaking, one is not a star, it is a planet, the planet Mars, one of the sun's family. Mars is a small planet, hardly one-sixth as big (in volume) as the earth. The other is the great glowing globe of incandescent gas we call the star Antares, so big that it would take one hundred million suns to match it in size. I will tell you later how you can find out which is Mars and which Antares.

This star Antares is one of the twenty brightest stars in the sky. Lying about half-way between the north pole and the equator we can see fifteen of them, including Sirius, the brightest of them all.

How many of these fifteen stars do you know? Ten? Five? One? It is rather disconcerting, isn't it? For, aside from the satisfaction such knowledge gives, all of us ought to know something about the stars, if only to keep out of trouble. Suppose your young son or daughter or your kid brother or sister were to ask you, "What star is that?" could you tell them or would you have to stall or hide the fact that you don't know? Or suppose you were lost somewhere. Could you steer yourself to safety by the stars, or would you, as so many poor devils have done, wander round and round, utterly bewildered for lack of this simple little bit of knowledge?

As a matter of fact, have you ever really seen the stars, or are you like the school teacher who on looking through the telescope at the Lick Observatory, exclaimed to the director, "Why! is that a star? I thought every star had five points!"

It sounds rather silly, doesn't it? Yet, just between ourselves, how much better could we do? What do we, you and I individually, know about the stars?

So, although my question may sound rather silly also, let me repeat it, "Have you seen the stars?"

"But of course I have," you may answer, "thousands of them." But have you? Not everyone has, you know. Very few people have

*A radio talk over station CFCT, Victoria, B.C., July 4, 1939.

really seen one single star, let alone thousands. In fact, without binoculars or a telescope, only a few hundreds—not thousands, but hundreds—of stars can be seen by anyone. Does that surprise you? None the less it is true.

But when we talk of seeing, perhaps you and I may not mean quite the same thing. Try this experiment some time. A few seconds after you have seen a friend look at his watch, ask him "What is the time?" It's odds on that he will look at his watch again before he tells you. Why? Because the first time he saw without seeing. The second time he had to know what he saw before he could put it into words.

That is what I mean by seeing the stars. It does not mean casually glancing at the sky to see if it be cloudy or clear. It means knowing that you see them. It means perceiving them. The word perceive means literally to take hold of, to grasp. Seeing the stars means looking with the earnest desire and endeavour to grasp what is there to be seen. If you do you can enjoy the most stupendous pageant of majesty and beauty that nature has to offer us: the nightly pageant of the stars.

"At such a time," as Maeterlinck says, "the immensities of space, the incomprehensible figures that describe the multitudes of the stars, their dimensions, their distances, do not concern us except as by their very incomprehensibility they may give us some faint notion of this infinity of which each of us is a part."

What though light, which can travel seven times round the earth in less than a single second, takes years or thousands of years to reach us from some star? What though the nearest star, the sun, is a million times as large as the earth or that other stars are a million times again as large? As we gaze into the starry sky such figures are of no more immediate interest than the date when Beethoven wrote his seventh symphony is to one enthralled by its mighty harmonies.

No, it is not figures about the stars but the stars themselves that interest us; the stars and their groupings in the heavens; those ancient constellations that were old before the race was born that builded ancient Babylon, old as Chesterton sings—

> Before the gods that made the gods
> Had seen their sunrise pass.

We want the same feeling of intimacy with them as we have with the flowers in our garden; not as botanical specimens but as living beauty of form and colour; as friends.

This spiritual knowledge of the stars, if I may so express it, is not difficult to achieve. One needs but to be interested and the knowledge comes almost of itself. The boy who knows the batting averages of his favourite players, the woman who knows the prices of hats in a dozen millinery shops, the man who can tell you the daily prices of stocks on exchange does not think it a difficult attainment, nor is it. They know these things because they are interested in them. Knowledge of the stars can be as easily gained.

"It sounds mighty fine," says someone. "I'd like to know some thing about it, but it's all far too deep for me. I could never grasp it."

Why is it that knowledge of the stars is almost universally believed to be beyond the ken of ordinary folk? It is utter nonsense, yet it seems to be accepted without question. People seem to think that knowledge, any knowledge of astronomy, not only demands a superlative knowledge of super-mathematics but ownership of a costly telescope into the bargain. It would be a poor lookout for most of us were that true. Fortunately it is false.

Aside from the fact that in the Telescope Section of the Royal Astronomical Society of Canada here in Victoria, almost anyone for a few dollars can build a far better telescope than was dreamed of by Galileo, whose primitive "optic tube" enabled him to make discoveries which revolutionized human thought, the pity of it is that because of this false notion about astronomy thousands of people old and young are depriving themselves of a hobby of surpassing interest and ever increasing enjoyment. Merely to have a nodding acquaintance with the stars is pleasant, but far greater is our enjoyment when we not only know their names and addresses, so to speak, but are able, when in due season we first glimpse a star rising through the luminous twilight of a quiet evening, to recognize it as an old friend returning after months of absence. Such knowledge affords a pleasure that must be experienced to be understood. To know, for instance, when we may see Arcturus, whose golden light was used, you remember, to open the World's Fair at Chicago a few years ago; and, as the twilight deepens into dark to see the

shimmering beauty of Berenice's Hair, that constellation which perpetuates the lovely legend of a woman's love and sacrifice for her warrior husband; know, too, when blue-white Spica comes and Cepheus with its pulsating star *delta*, first of many by which we now can tell the distances of far-off universes, one of which, glimmering faintly in the constellation called Andromeda we can see even with the naked eye; and Perseus, slayer of the sea monster, bearing in his sword-hilt clusters of glorious jewels and in his belt that once mysterious star called by the Arabs of old Al-gol, the demon, which every three days, more regularly than most clockwork, dims its light; and Castor and Pollux, twin guardians of the sailormen who plied the middle sea and watched

> the Pleiads, rising thro' the mellow shade,
> Glitter like a swarm of fire-flies, tangled in a silver braid.

When thus we know the constellations, the stars that compose them cease to be mere twinkling points of light from some far, unknown source, they take on personality; they become friends. And they never intrude, never bore us, never disappoint. Always the more we know of them the more we enjoy them. And the knowledge is free to all.

It has been my privilege to tell you of a few things which make the study of astronomy so attractive as a hobby for everyone. In these anxious days when the pressure of events is increasingly severe upon each of us, the need of adequate relaxation and refreshment is vital. The popularity of the movie testifies to this need but does not satisfy it; nor does the usual round of golf or bridge. True recreation demands more than mere amusement, it requires a hobby; doing something that not only refreshes us when the day's duties are done but occupies us beneficently as well as pleasantly. The true hobby is work, work of our choosing, done not from necessity nor hope of financial gain, but simply for the joy of doing it.

It is told that the great experimenter Michelson, when asked in his later years why he was again preparing to repeat with even greater care and more exquisite refinement the exacting experiments by which he had already determined the speed of light to an accuracy of one in ten thousand, replied—"Well, first of all I shall have so much fun doing it." It would be difficult, I think, to find a better example of a hobby.

"No one in the world can be happy without a hobby, the pursuit of some subject in which he is intensely interested. When in addition to being an innocent diversion ours is a useful study, we and our fellow mortals are alike gainers." If to these words, written some fifty years ago, we add that it must gain in interest with the years, be not too expensive, nor require too much of our time and energy, we shall have the picture of the perfect hobby.

With all sincerity I recommend to you the study of astronomy because, of the pursuits available to both young and old, it best fulfils these requirements for a hobby.

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# TWENTY-EIGHTH ANNUAL MEETING OF THE AMERICAN ASSOCIATION OF VARIABLE STAR OBSERVERS

By D. W. Rosebrugh

The twenty-eighth annual meeting of the A.A.V.S.O. was held at the Harvard College Observatory on October 13, 14 and 15, 1939. The Association accepted the kind invitation of the Toronto Centre of the R.A.S.C. to hold its May, 1940, meeting in Toronto. Reports of the various committees were received.

*Occultation Committee—*

Dr. Alice Farnsworth, Director of Mount Holyoke Observatory submitted the report of the Occultation Committee at the Saturday morning session at which President Charles W. Elmer presided. A new method of reducing the observations has cut the time of calculation to one sixth of the former amount. The Norwalk, Connecticut, Astronomical Society had been of assistance in developing this new mathematical short cut. One hundred and thirty-four reductions of 67 occultations were made. This represents 7 per cent. of all the work done in the entire world upon this subject. The completed observations and reductions are only the raw material from which Dr. Dirk Brouwer of Yale, Second V.P. of the A.A.V.S.O., obtains the finished products which are the motions of the earth and moon.

*Nova Search Committee—*

Mr. Roy A. Seely, Chairman of the Nova Search Committee, submitted suggestions for a new and improved programme for this work. The co-operation of amateurs and astronomical clubs in this work would be welcomed, he said.

*Photographic Committee—*

Dr. A. E. Navez reported that the Photographic Committee has 10 main fields and many sub-fields ready for the study of variable stars by photography. Colleges, astronomical societies and amateurs with photographic equipment are being asked to undertake this work.

*Variable Star Observing—*

Mr. Leon Campbell, Recorder and Pickering Memorial Astronomer, submitted his report. Three of the 4 R Coronae Borealis stars have "acted down" during the last year. Z Camelopardalis and SS Cygni are being carefully followed. The 135 observing amateur members had submitted 53,457 observations on variable stars during the year, bringing the total received since 1911 to 750,000. Signor Eppe Loreta, Bologna, Italy, had been first this year with 5692 observations. Requests for the observations upon variable stars made by the A.A.V.S.O. had been received from Mount Wilson and other observatories where variable stars are being studied.

Various amateur members submitted papers describing methods of combating dew on diagonals and eyepieces; the methods to be followed in recording observations of aurorae for the Cornell-National Geographic Society study of aurorae; the cepheid $\beta$ Doradi; and the recent convention of amateur astronomers held at the New York World's Fair.

Dr. and Mrs. Shapley entertained the Association at luncheon in the Observatory Residence.

Dr. Cecilia Gaposchkin reported upon the work of the Milton Photographic Variable Star Bureau which is studying intensively the Harvard photographic plates for the last 50 years. The details of various eclipsing variable stars have been fully computed, but some present irregularities in their periods. In the case of RZ Cassiopeiae the irregularities were presumably caused by rotating apsides but AL Scorpii presents unexplainable irregularities in the timing of its eclipses which cannot be attributed to rotating apsides or to the presence of a third star in the binary.

Dr. Sergei Gaposchkin reported that a study of the galactic distribution of 250 eclipsing variable stars indicated that they were distributed in space in the same lens-like form that the galaxy is known to possess, although a curious paucity of these stars seems to exist in the direction of the constellation Vela.

The centenary of the establishment of a chair of astronomy at Harvard was celebrated at Dana House, on the Harvard campus, which was the site of the first observatory established in 1839. Miss Elizabeth Bond, granddaughter of William Cranch Bond, the first

Harvard astronomer, described the observatory as she remembered it in her youth and pointed out the site of the transit at that time which was just about where most of her auditors were sitting.

Dr. Shapley listed the five astronomical highlights of the year as, the development by Dr. Bethe of Cornell of the hydrogen-carbon-helium cycle which supplies the sun with energy as described in the September issue of this JOURNAL on page 298; the completion of the McDonald Observatory with its fine spectrographic equipment; the conclusion that super-novae differ principally from novae by a greater rate of expansion; the more detailed classification of galaxies by Dr. Hubble based upon more complete data; and the discovery by Dr. Luyten that the number of stars of each magnitude increases steadily as we proceed towards fainter magnitudes, so that it is now known that there are more stars of plus 14.5 absolute magnitude (1/4000 that of the sun) than there are of the sun's brightness, while there are more stars of the sun's brightness of absolute magnitude 5½ than there are of absolute magnitude zero.

Mrs. Winifred Kearons, the Rev. Mr. Caspar Gregory, Mr. Claude B. Carpenter and Dr. Charles H. Smiley were elected to the Council by the vote of the members at large. The Council then elected Dr. Helen S. Hogg, David Dunlap Observatory, Richmond Hill, Ontario, as President; Dr. Dirk Brouwer, Yale, as First Vice-president; Mr. Joseph W. Meek, Tucson, Arizona, as Second Vice-president; while Mr. Leon Campbell, Mr. Percy W. Witherell and Mr. David W. Rosebrugh were re-elected Recorder, Treasurer and Secretary respectively. As the Secretary commented at the Annual Banquet, Canadians, former Canadians and Canadians by adoption are strongly represented among the guiding spirits of the A.A.V.S.O., for the President, Mrs. Hogg; the Secretary, Mr. Rosebrugh; and the Chairman of the Nova Search Committee, Mr. Seely, all fall in this category.

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## METEOR NEWS

**Observations relating to meteors and meteorites are cordially invited.**

### Persistent Trains Observed in Orillia

Three interesting observations of the drift of persistent trains have been made recently by Mr. Jack Grant, observing near Orillia, Ont. His position was lat. 44° 38′ N., long. 79° 28′.5 W. Since photographic observations were being carried out when these meteors were seen, and since they were outside the camera fields, accurate plots of the meteors themselves were not made. The trains, however, were observed in 8-power binoculars of aperture 1.2 inches, field 7 degrees in diameter. Details of the observations are listed below.

*I Oct. 22, 1939, 4*$^{h}$ *34*$^{m}$ *05*$^{s}$ *E.S.T.*, an Orionid of magnitude −3, red in colour. The persistent train remained near the end of the visual path, which was long, and brightest at the position of the train. The train was visible in binoculars for 3 minutes.

*II Nov. 17, 1939, 2*$^{h}$ *14*$^{m}$ *22*$^{s}$ *(or 18*$^{m}$ *57*$^{s}$*) E.S.T.*, a Leonid, definitely brighter than mag. −3, green in colour, path length 5 degrees. This meteor was observed very low over the eastern horizon at an altitude of approximately 4 degrees. The uncertainty in the time for this and the following meteor was due to the fact that at some unknown time during the observations the watch stopped for slightly over four and a half minutes and then started again. The train was visible in binoculars for 5.5 minutes. It is probable that this meteor and its train were observed in the New England States and it must have been a brilliant sight where it passed near the zenith. Mr. R. M. Dole of Portland, Me., reports seeing a 41-minute train from a meteor of mag. −10, appearing at 2$^{h}$ 08$^{m}$ on this night. This may be the same meteor in spite of the apparent discrepancy in the reported time.

*III Nov. 17, 1939, 4*$^{h}$ *25*$^{m}$ *39*$^{s}$ *(or 30*$^{m}$ *14*$^{s}$*) E.S.T.*, a Leonid, brighter than mag. −3, greenish, path 15 degrees long. This also

appeared fairly low in the east, altitude 11 degrees. The persistent train appeared near the end of path and was visible for 9 minutes in the binoculars.

The train drifts observed by Grant are illustrated in Figure 1. Probable positions of the meteor paths have been inserted by the

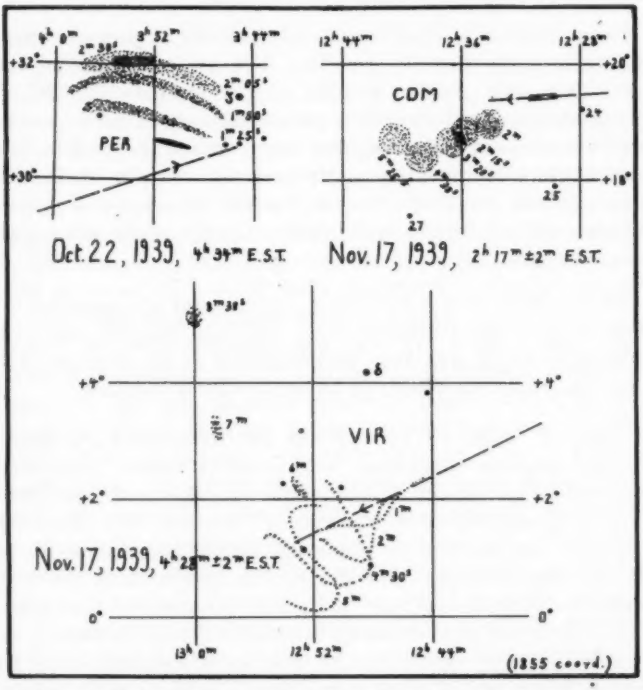



FIGURE 1.—Observation of three train drifts by Mr. Jack Grant at Orillia, Ont. The times beside the train plots are intervals since the meteor appeared.

writer as broken lines. These were drawn assuming a standard radiant and approximately uniform train drift. In the absence of second observations of these three meteors we may assume the trains at the normal height of 90 km. and compute minimum possible drifts. These are

| *Meteor* | *Min. Drift* | | *Direction* |
|---|---|---|---|
| I | 105 km/hr | to | N |
| II | 220 | | SE (uncertain because of distance) |
| III upper part | 155 | | S |
| lower part | 180 | | NNE |

The third meteor shows an interesting differentiation in the direction of drift for two parts of the train. It is hoped that other observations of these meteors may make it possible to compute actual heights for the trains. The writer will be glad to hear from any of the readers of the JOURNAL who observed them.

PERSISTENT TRAINS OBSERVED IN BOLOGNA, OCT.–NOV., 1939.

M. Eppe Loreta in Bologna has again contributed some fine observations of train drift. The four train drifts here discussed make a total of 16 drifts observed by Loreta and reproduced in these columns since the beginning of 1936. This number gives good evidence of the assiduous way in which M. Loreta continues with his meteor observing. It is only by long hours of continual watching that one observer can record 16 meteor train drifts in four years.

In the case of the four trains reproduced in Figure 2, it is unfortunate that observations made outside Bologna are lacking. In connection with the first a faint cloud near Triangulum was observed by G. Zaffi at Ferrara (44 km N.E. of Bologna) at approximately $23^h\ 55^m$, some minutes after it had disappeared in the binoculars used by Loreta. Zaffi's observation was made with a telescope almost 5 inches in aperture and undoubtedly was of the last remaining portion of the meteor train though at the time it was thought to be a comet. It was found impossible to use this observation in any determination of train height, probably owing to the difference of time. Loreta's notes on the four meteors in question are summarized below.

*I Oct. 20, 1939, $23^h\ 36^m$ G.C.T.*, an Orionid of mag. −5, leaving a long train visible 3 minutes to the naked eye and 6 minutes in the binoculars. The lower part of the train appeared as a diffuse line to the eye but after 1 minute it appeared in the glasses as

two distinct parallel lines, an effect previously noted by Trowbridge* and others and supposedly due to the presence of a hollow cylinder of luminous gas which, when seen from the edge, would

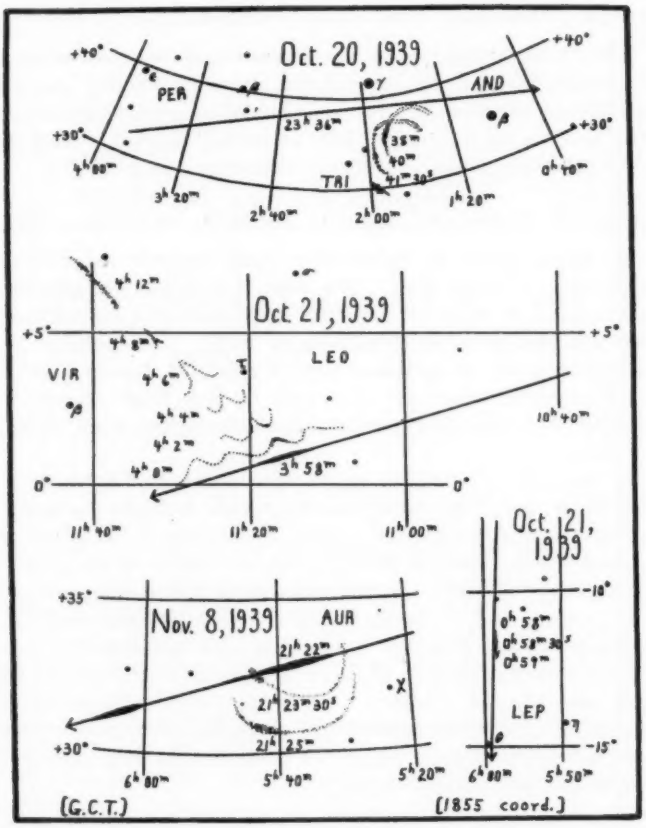



FIGURE 2.—Observations of four train drifts by M. Eppe Loreta at Bologna. All times on the diagram are G.C.T.

*Ap. J. vol. 26, p. 95, 1907

appear stronger at the borders thus giving the effect of two parallel lines.

*II Oct. 21, 1939, 0h 58m G.C.T.*, an Orionid of mag. 0, train visible 10 seconds to the naked eye and 60 seconds in the binoculars.

*III Oct. 21, 1939, 3h 58m G.C.T.*, an Orionid reaching a maximum brightness of mag. −7. Two maxima of intensity were observed, the train (visible 2 minutes to the naked eye and 15 minutes in the binoculars) being most brilliant at the first of these. Loreta notes that the waves in the train as plotted at 4h 0m are not of equal length and are probably not due to rotation of the original particle.

*IV Nov. 8, 1939, 21h 22m G.C.T.*, a bright meteor, mag. −2, with two maxima of intensity. Train visible 25 seconds with the naked eye, 190 seconds in the binoculars. Loreta considers the radiant of this meteor as probably near Omicron Persei.

Minimum possible velocities of drift were computed for the above four trains, assuming that they were at the normal height of 90 km. These gave the results listed below:

| *Meteor* | *Min. Drift* | *Direction* |
|---|---|---|
| I | 160 km/hr | to S |
| II | 150 | S |
| III | 150 | N |
| IV | 100 | S |

It is interesting to note that on Oct. 20-21 two distinctly different directions of drift were noted. These may very well have occurred at different levels and give further evidence of cross-currents which have been even more strikingly demonstrated in Grant's third train drift, noted above.

### Russian Meteorites for 1938

A reprint from the Russian Journal "Science and Life", No. 4, p. 20, 1939, has recently been received from Dr. E. L. Krinov in which, under the title "New Meteorites of the U.S.S.R.", he dis-

cusses four 1938 additions to the list of Russian meteorites. The first of these is the fall Lawrentjevka, No. 90 on the list published by Astapowitsch in the JOURNAL, vol. 32, p. 195, 1938, and referred to again in vol. 33, p. 58, 1939. Details of the other meteorites described by Krinov are listed below, the numbers from the list by Astapowitsch being continued serially.

(91) *Pavlodar*, Kazakhstan Socialist Republic,
$\varphi$ 52° 37′ N
$\lambda$ 51° 34′ E
T 1933, May 23, $13^h\ 40^m$ (kind of time unknown).
White chondrite, single stone, original weight 120 gm. Four fragments, total wt. 22.5 gm., in the East Kazakhstan Museum. Additional reference, Ac. Sc. U.S.S.R., vol. 20, no. 7-8, p. 585, 1938.

(92) *Kukshin*, Nezhinskogo district, Chernigovsky province,
$\varphi$ 52° N (approx.)
$\lambda$ 32° E (approx.)
T 1938, June 11, $14^h$.
Stone, total weight recovered 2262-5 gm.

(93) *Zhovtnevy*, Stalin district, Ukrainian Soviet Socialist Republic,
$\varphi$ 47° 35′ N
$\lambda$ 37° 15′ E
T 1938, Oct. 9, $0^h$ U.T.
Grey chondrite, four stones found, total wt. recovered 30,741 gm. Additional reference, Ac. Sc. U.S.S.R., vol. 22, no. 7, p. 436, 1939.

As noted in the JOURNAL, vol. 33, p. 57, 1939, Dr. Astapowitsch reports a meteorite shower near Odessa on Dec. 2, 1938. This will probably be No. 94 in the complete list of Russian meteorites.

P. M. M.

# REVIEW OF PUBLICATIONS

*Planetary Co-ordinates for the Years 1940-1960, referred to the Equinox of 1950.0.* Prepared by H.M. Nautical Almanac Office. London. Pp. xvi and 150, $9\frac{1}{2} \times 12$ in. Price, 17s. 6d. net.

This volume is a continuation of Planetary Co-ordinates for the Years 1800-1940, published in 1933 and reviewed in this JOURNAL, vol. 27, p. 344. The two volumes taken together include all the basic planetary data required in the computation of planetary perturbations from 1800-1960.

The quantities tabulated for each planet, Venus, Earth, Mars, Jupiter, and Saturn, are referred to the mean equinox of 1950.0.

$l$ = heliocentric longitude
$b$ = heliocentric latitude
$r$ = radius vector
$x, y, z$ = heliocentric rectangular co-ordinates
$X, Y, Z$ = attractions of the planet on the sun.

Throughout the natural values of the quantities are given as the data are meant to facilitate machine computation. The quantities are tabulated at 10-day intervals. Similar tables with the interval 40 days are tabulated for the planets Uranus and Neptune.

The subsidiary tables specially constructed to facilitate the computation of perturbations by the methods of Encke and Cowell which appeared in the earlier volume are repeated. These include tables for the mean obliquity of the ecliptic, ecliptic and equatorial precession, the reduction of star positions from 1875, 1900 and 1925 to 1950, masses and attractions, formulae of mechanical integration and tables for their application.

The binding is similar to the earlier volume, durable and attractive.

R. K. Y.

*Seven-figure Trigonometrical Tables for Every Second of Time.* Prepared by H.M. Nautical Almanac Office. Pp. 101, $7 \times 11$ ins. H.M. Stationery Office, London, 1939. Price, 10s. net.

The recent rapid increase in the use of computing machines has

created a demand for tables of natural trigonometrical functions. This demand has been met for general computation by tables of these functions for angles expressed in degrees, minutes, and seconds of arc, and for angles in radian measure, to varying numbers of decimals. A definite astronomical need has been felt for such tables with the argument in time, to avoid laborious transformation from time to arc and arc to time. A number of years ago the Nautical Almanac Office prepared such tables by machine interpolation, for its own use. The task of publishing these for general use has finally been completed.

The main table contains, for every second of time, for one quadrant, the natural values of the sine, tangent, and cosine to seven decimals, and of the cotangent to a varying number of decimals. The number of decimals in this case is selected by several criteria, and gives roughly the same number of significant figures in the cotangent as in the corresponding tangent.

An auxiliary table gives the function $x^s \cot x^s$ to three decimals or eight significant figures, for every second of time up to 30 minutes. This permits the cotangent of small angles to be readily determined to seven significant figures.

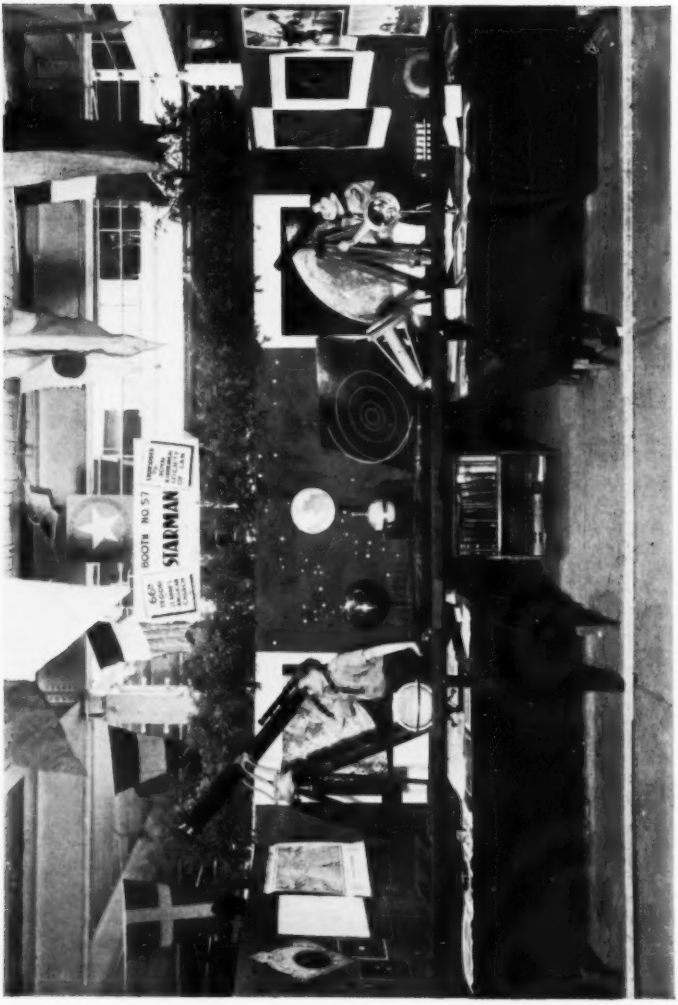
The table is well arranged, clearly printed, and serviceably bound, and should greatly facilitate computations of astronomical formulae involving right ascension or hour angle.

F. S. H.

*Actualidades Cientificas* by Ignacio Puig, S.J. Pages 232 and index. 1939.

This is No. 11 of the Scientific Publications of the Observatory of Cosmical Physics of San Miguel, Argentine Republic. Father Puig, the director, has already published two volumes of a similar nature. They all consist of articles dealing with modern science which were contributed to "El Pueblo" of Buenos Aires. Among the subjects may be mentioned: the photo-electric cell, gigantic meteorites, the discovery of new radio-elements, the theory of hyperspace, the sun and cancer, investigations of the upper atmosphere, atomic bombardment (featuring the cyclotron), and many other subjects of the present day. To those who read Spanish this volume will be found full of interest and information.

C. A. C.




The Starman's Booth at the Scout Cyclorama in Toronto, April, 1939.

# NOTES AND QUERIES

**Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.**

## The Starman's Badge at the Scout Cyclorama (with Plate XIV)

In April, 1939, the Boy Scouts Association of Toronto staged a great cyclorama in the Coliseum in which each scout merit badge was represented by a booth illustrating activities in the corresponding field of study. The attendance totalled over 100,000 and great variety and ingenuity in the planning of the exhibits were in evidence. These displays ranged all the way from the Photographer's Badge, with a working darkroom walled on one side with red cellophane so that spectators could observe the actual processing of photographic material, to the Safety Man's Badge, where, among other things, a wrecked car gave mute witness to the results of carelessness in driving. The Toronto Centre of the Royal Astronomical Society sponsored the Starman's Badge and a view of this booth is shown in Plate XIV. Models of orbits, planets, the moon, telescopes, and meteorites were displayed as well as a 2-inch and a 4-inch telescope and many interesting astronomical diagrams and photographs. Two particular fields of activity, open to most scout troops, were stressed. These were first, co-operation in programmes of meteor observation directed from some observatory; and second, the making of telescopes. This astronomical exhibit was planned and arranged by Mr. Jack Bougard, assisted by Mr. M. H. Watson, both members of the Toronto Centre, and the great interest it created at the cyclorama does them both credit. Unofficial rumour has it that the Starman's Booth was considered one of the best displays at the cyclorama and it resulted in several new members for the Society and is a good example of one way in which astronomy may be popularized.

P.M.M.

## Astronomy in New Zealand

The Report of the Dominion Observatory at Wellington, N.Z., for the year 1938 shows that scientific work of a considerable variety is being carried on by our antipodean friends. The distribu-

tion of accurate time by radio, telegraph and telephone is an important part of the observatory service. In addition observations are regularly made on the sun, on the occultations of stars, and on auroral displays in the southern sky. The observatory co-operates with the New Zealand Astronomical Society, the Wellington Philosophical Society and the Wellington City Observatory.

Earthquakes are not infrequently felt in New Zealand and records of them are continuously obtained and studied. In addition to the Dominion Observatory, Wellington, and the Magnetic Observatory, Christchurch, there were eleven subsidiary seismograph stations in operation during 1938. A total of 132 shocks were reported.

Along with the above Report came a list of publications which have been issued by the Dominion Observatory. There are 141 items, the first being in 1913. These publications are now issued in four series: A. Astronomical, S. Seismological, T. Time Service, R. Annual Reports. They are generally printed in the New Zealand Journal of Science and Technology, but some appear in the New Zealand Official Year-book or in the Annual Report of the Department of Scientific and Industrial Research.

C. A. C.

"When the Earth Split"

A Query bearing this title was printed in our October issue together with a request for references on the subject. Two replies drew attention to a book by A. Wegener entitled "Die Entstehung der Kontinente und Ozeane." Also, a small volume entitled "Observations on the Temple of Serapis at Pozzuoli near Naples with an attempt to explain the causes of the frequent elevation and depression of large portions of the earth's surface", by Charles Babbage, 1847, was placed in the writer's hands. This author discusses the action on an elevated table-land adjacent to the ocean. By the wearing down of this land, the building up of the ocean bed and the consequent change in the isothermal surfaces some miles below within the earth he argues that the surface of the dry land of the ocean bed may be raised or lowered in long periods of time. In an addendum Babbage refers to the investigations of Darwin based on his travels 1826-36 as confirming his reasoning.

A brief statement of Wegener's views is given by Dr. B. Haurwitz, of the Meterological Office, Toronto, as follows:

The hypothesis concerning the separation of the two large continental masses and the formation of the Atlantic ocean has been the subject of a book by the German meteorologist, A. Wegener, who died some years ago on his second Greenland expedition. The title of this book is "Die Entstehung der Kontinente und Ozeane", 3rd ed., Braunschweig, 1922. I believe there is an English translation. Very briefly sketched, Wegener's theory is based on the idea that the continental masses, which are lighter than the material of which the ocean bottom consists according to seismological evidence, are swimming in the heavier material. Since the centre of gravity of the swimming masses does not coincide with the centre of gravity of the displaced sub-continental masses there exists a force which pushes the continents towards the equator. The intensity of this force was different in different parts of the original continent which led to the split. There is furthermore a force which causes a drift towards the west and some observations of the geographic longitude seem to indicate such a drift. According to Wegener the Rocky Mountains are, for instance, evidence of such a drift which caused the uplifting and mountain formation on the western edge of the continental mass. This hypothesis has received a good deal of attention, acclamation and criticism from geologists and geophysicists.

Mr. A. L. Killick of New Westminster, B.C., suggests, in addition to Wegener's book, "The Earth", by Harold Jeffreys, which, as he says, is hard to read (in spots); and "Earth, Radio and the Stars" by H. T. Stetson. He further remarks:

I am afraid I cannot agree with your correspondent's idea of a tremendous explosion in the early history of our Globe; such a force acting on the viscid magma would not tend to eject a mass of matter from one spot but would rather rupture the globe as a whole.

On the other hand, the "Resonance Theory" suggested by Fisher, presents a more reasonable picture of this early rupture. As the name implies, resonance acting on the molten mass, encased only in a thin crust, would cause the expulsion of a body similar to the moon. This body would carry with it a large part of the crust together with part of the magma.

A survey of a few statistics show that known facts dovetail very nicely with this theory; land area 29 per cent, and the sea 71 per cent, earth's mean density 5.52 with the continents averaging less than 3 and ocean beds ranging around 4. The moon's mean density 3.33; from this it is reasonable to suppose the moon to be composed of material drawn chiefly from the earth's crust together with some magma. The remaining crust forms the continents as we know them today.

Wegener's theory of "Continental Drift" presumes the present disposition of the continents to be the result of a slow westward motion of the land masses during the late geological eras. Such a theory has the support of recent geodetic

surveys in both Greenland and Scotland, however, geology reveals that apparently the continental positions have been constant throughout the entire history of our earth. Well the final word will probably never be said and one must keep an open mind on such controversial subjects.

An entirely new approach to the subject was made in a letter from a correspondent who says:

If one reads chapter X of the Book of Genesis the rather startling verse 25 is found:—"And unto Eber was born two sons; the name of the one was Peleg (Division) for in his days was the earth divided, and his brother's name was Joktam". This verse also occurs in I Chronicles, ch. 1, v. 19. No other reference to this remarkable division occurs in the Scriptures, according to my knowledge but it seems to me this small mention of this remarkable event, which occurred after the Deluge, at least occurred during the time of man upon the earth and not in the dateless past before the earth as we know it came into being.

Whether F. T. S., who offered the Query is satisfied or not, he will perceive that the subject has been under consideration for a long time. Continued observation and investigation will support or disprove the views which have been propounded.

In this present issue is an article in which the question is discussed.

C. A. C.

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